PRACTICAL TELEGRAPHY.

A HANDBOOK

OF

PRACTICAL TELEGRAPHY.

BY

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PUBLISHED WITH THE SANCTION OF THE

CHAIRMAN AND DIRECTORS OF THE ELECTRIC AND INTERNATIONAL TELEGRAPH COMPANY.

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PREFACE.

THE intention of the Author has been to give information to members of the Telegraph Service, and to those interested in Telegraphy, concerning—

The Electrical Laws upon which the system depends:
The Methods of Discovering Faults:
The Practical Management of Apparatus:
And the Construction of a Line.

He has attempted to supply in some measure that technical knowledge which has hitherto been attainable only by means of verbal instruction or actual experience.

With a view of rendering the work more acceptable to practical men, the Author has endeavoured, as far as was possible, to make the language popular rather than scientific.

The Author has to acknowledge his obligation to the works of Blavier and Gavarret on the Telegraph; to the treatises of De la Rive and Gavarret on Electricity; to Faraday's Experimental Researches; the Government "Submarine Report," and to his friends Mr. C. F. Varley and Mr. W. H. Preece. He has also to express his deep sense of the honour conferred upon him by the Chairman and Directors of the Electric and International Telegraph Company, who have approved the work and adopted it for the use of their staff.

BRISTOL, *October*, 1863.

INTRODUCTION.

THE apparatus employed to transmit intelligence by means of electricity may be divided into two great classes—telegraphs whose signals are transient, and must be read off one by one as they appear, and those which record their signals permanently, so that they can be read at leisure.

The instruments used in this country, of the first class, are the double and the single-needle telegraphs of Cooke and Wheatstone, used by the Electric Telegraph Company and the South Eastern Railway Company,—the single needle requiring one wire and the double needle two,—and a modification of the single needle used by the Magnetic Telegraph Company.

This class of instrument indicates letters by the separate or combined movements of their needles or pointers, are very simple in their construction, little liable to get out of order, and therefore most suitable for the business of a railway where skilled clerks cannot be employed.

The telegraph of Professor Wheatstone, in which a hand points to the letter itself on a dial, is gaining ground for private use; and the Bell telegraph of Sir Charles Bright,

which reproduces the signals of the Magnetic Company's needle instrument by strokes upon two bells of different pitch, one of which represents the movements of the needle to the left, the other the movements to the right, is extensively used by the Magnetic Company, and has the advantage of leaving the hands free to write down the message as received.

The instruments of the second class are the so-called printing telegraphs of Morse and Bain, which *record* the signals received in an alphabet composed of dots and strokes. These instruments are used on all the important circuits of the Electric Company, and Morse's system is generally employed throughout Europe.

The type-printing instrument of Professor Hughes has been introduced; but it is said not to be very successfully worked at present. It records the message in ordinary letters, which can, of course, be read by any one.

Professor Wheatstone has also introduced a type-printing instrument for private use.

The commercial value of an instrument does not depend upon the use of the ordinary alphabets, but upon the amount of work it will turn out, and its accuracy and freedom from derangement. The Morse instrument is at present unsurpassed in these respects, and it has been found that its introduction upon a circuit previously worked by the needle system reduces error to a very considerable extent. This arises from its signals being *recorded;* they can be read calmly and without flurry, and should an error arise it can be traced to the person in fault, thus inducing a far greater sense of responsibility.

It may be interesting to place on record the speed attained by the double needle and Morse instruments in a *fair* trial of speed.

The highest speed on a circuit of a little under 200 miles was :—

Double Needle .	35 words per minute.	
Printing . .	38	,,

Average of between two and three hours' continuous work reporting a speech of Mr. Bright :—

Double Needle .	24·3 words per minute.	
Printing . . .	26·5	,,

and for a circuit of more than 400 miles :—

Printing, average speed . . 24·5 words per minute,

clerk reading from the manuscript of the "Times" reporter —not always very legible.

PART I.

SOURCES OF ELECTRICITY.

1. Electricity exists in every substance in nature, but is not evident to our senses until its state of rest or *equilibrium* has been disturbed.

2. Friction and chemical action are the most ready means of disturbing this *neutral* state. When a dry glass tube, a stick of sealing-wax, or an ebonite comb, is rubbed on the coat sleeve, it attains the power of attracting light substances. It is said to have become electrically excited, and its electricity manifests itself in causing attraction.

3. Lay two narrow strips of very thin gutta percha side by side, and draw them briskly between the fingers; they will repel each other, but the excited glass tube will *attract* them.

Make an electroscope by suspending two balls made of elder-pith by dry sewing silk, bring them near each other, and touch both with the glass; they repel each other. Touch them with the ebonite; they again repel. But touch one with the glass, the other with the ebonite, and they *attract* each other (17).

4. It appears, then, that there are two conditions or states

of electrical excitation, or, it may be, two kinds of electricity —the one produced by rubbing glass, the other by rubbing ebonite or sealing-wax. The first is called "*positive*" or "*plus*," and is designated by the sign +; the second "*negative*" or "*minus*," designated by the sign −. These terms are entirely arbitrary; all that is meant by them is that the two states are *opposed*, not that there is more electricity in the one than in the other.

5. Bodies *similarly* electrified, both positively or both negatively, *repel*. Those dissimilarly electrified, one + the other −, *attract*.

An ebonite pocket comb is the most convenient substance for obtaining negative electricity, and a glass rod for positive. The glass must, however, be well dried and warmed.

6. A metal rod held in the hand and rubbed exhibits no signs of electricity; it will neither attract nor repel.

It does not, however, follow that no electricity has been set free by the friction, for

7. Metals and some other bodies have the property of allowing electricity to diffuse itself freely throughout their whole substance, and are termed *conductors*.

Glass, gutta percha and ebonite, offer very great resistance or opposition to this diffusion, and are called *non-conductors* or *insulators*. When a conductor is fixed or supported upon a non-conductor it is said to be *insulated*.

8. Thus, when the metal rod is rubbed, the electricity not only diffuses itself over its surface, but over the body of the person holding it, and the earth, so as to restore equilibrium (1); for metals, the human body and the ground are *conductors*. On the contrary, when the glass or wax is rubbed, the electricity does not diffuse itself, but remains where it was produced, glass and wax being non-conductors.

If the metal rod be insulated by being fixed on a glass

handle, when rubbed it repels or attracts like the glass, but in a less degree. The electricity cannot escape over the insulating handle, and is confined to the rod.

9. In order to deprive a non-conductor of the electricity excited on its surface we must touch every part of it with the hand, or some other conductor. Whereas, a conductor can be deprived of its charge by touching one point of its surface only (8).

10. But the division of substances into conductors and insulators is not absolute. There are few (if any) bodies which are perfect insulators, or which do not conduct *at all* under any circumstances, while even metals, the most perfect of all conductors, offer a certain resistance, or in other words, insulate slightly. The terms imply a difference in degree only—good insulators are bad conductors, and good conductors bad insulators. Each of the substances in the following table conducts better than that which precedes it.

The first on the list is the best insulator, the last is the best conductor :—

Ebonite	Dry air	Mercury
Shellac	Porcelain	Platinum
India-rubber	Dry wood	Lead
Gutta-percha	Dry ice	Iron
Resin	Stone	Tin
Sulphur	Pure water	Zinc
Wax	Melting ice	Gold
Glass	Sea water	Silver
Silk	Saline solutions	Copper (pure)
Wool	Acids	
Dry paper	Charcoal or coke	

11. Friction, as has been seen, is one means of disturbing

the ordinary electric state of bodies, and of producing in them an electric *tension* or *strain*, or, as is sometimes said, of decomposing the electricity naturally existing in them into its two component parts. These terms, like those before mentioned (sec. 4) are used for convenience only, and may or may not be really correct.

12. When an ordinary electrical machine with an insulated rubber is set in motion, the equilibrium is disturbed at the parts which rub against each other. The cushion takes a –, the cylinder a + tension, and they may be called the negative and positive *poles* of the machine. The cylinder communicates its + tension to the conductor, which then becomes the positive pole, and a pair of pith balls hung upon it will *repel* each other, while a ball hung on the conductor will *attract* one hung on the rubber. (2, 3, 5.)

13. So long as the poles remain insulated, the friction increases their tension, and the electricity remains in the "static" condition (static meaning "standing still," or "not in motion") until the tension becomes so great as to cause it to dart in a spark between the rubber and conductor.

14. If the rubber and conductor are connected by a wire, the electricity passes as a *current* through the wire between the conductor and the rubber, until equilibrium is restored (1.8), and is then said to be in the "dynamic" or "working" condition.

15. The term current does not imply the actual passage of any fluid or gas, but a simple transfer of force, an action which is progressive in its nature, like the passage of light through space, or of heat through a bar of metal.

16. Chemical action is another means of producing electrical tension.

When two metals are immersed in a liquid which act

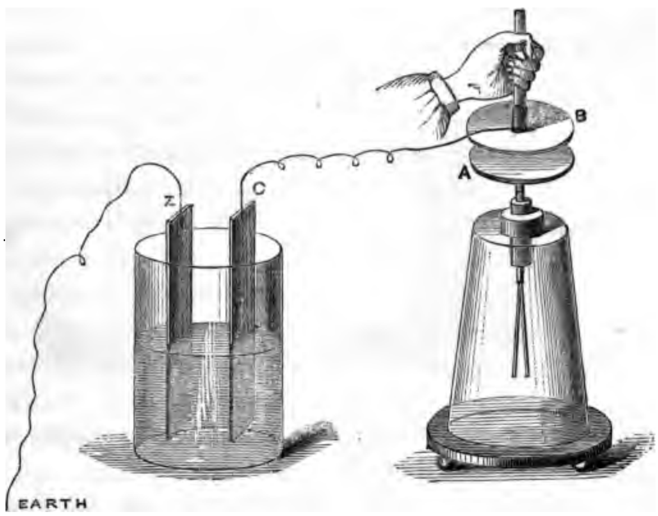
chemically more upon one than upon the other, they take opposite electric tensions, that which has the most affinity for oxygen becoming + (or positive), that having the least affinity – (or negative).

When zinc and copper are placed in dilute sulphuric acid, the copper which is not dissolved becomes –. The zinc which is dissolved, is +.

In cases where both metals are attacked, one more so than the other, that most acted on becomes positive, the other negative, and the force of the pair is the balance of these two actions. If both are equally affected, or neither of them attacked, there is no electric action.

17. So long as the two plates are not connected by a conductor, the electricity is in the *static* condition, and by proper means may be made to produce attraction and repulsion, so as to cause the pith balls, or gold leaves of an electroscope to diverge (3). The tension, however, is extremely feeble, compared with that of electricity evolved by friction. The best form of electroscope is two strips of gold leaf gummed to the opposite sides of a piece of card. The card should be in metallic connection with a piece of wire insu-

lated with ebonite or sealing-wax passed through a hole in a glass shade (a glass flower pot answers very well) and terminated by a knob. If the knob be touched with an excited rod of glass or ebonite, or if one pole of an insulated battery be connected by a wire to the *electroscope,* its leaves will diverge (3), and if the other pole be put to earth the divergence will increase (26). The greater the number of cells in series the greater the divergence, but an increase in their size will not affect it. The amount of divergence is a measure of the *tension* of the battery (13).



If a *condenser* be attached to the apparatus it will be acted upon by a very small number of cells. Cut out two discs of sheet zinc, flatten them, fix one (B) on an insulating handle, attach the other (A) to the wire of the electroscope. Drop three small pieces of hot sealing-wax on A, so that if B be placed on it the two shall lie as closely together as possible without touching.

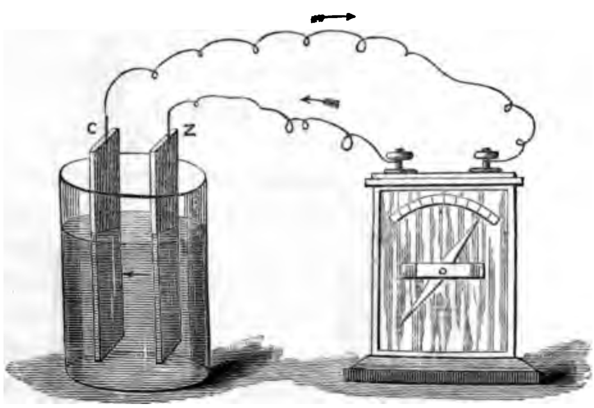
Place B upon A, connect B with one pole of the battery,

and touch A with the finger. Remove the finger, lift off B by its handle, and the leaves will diverge.

Thus the repulsion of light bodies can be caused by the battery, as well as by friction.

18. If the two plates be connected by a wire, a current or transfer of electricity is established, which lasts until the chemical action ceases (14).

The metal most attacked determines the direction of the current. When zinc and copper are used the + current



passes from the zinc through the liquid to the copper and thus leaves the battery by the − metal.

(See De la Rive, vol. 2, pp. 662, 663: English Translation.)

The copper end of a battery is therefore called its **positive** *pole*, and the zinc end its negative *pole*.

19. The difference between the machine and the battery is this. The electricity of the former is high in *tensi*... or power to overcome resistance, but very small in *qua*... so that no appreciable ... *maintained* in ... conductor connecting ... in the ...

tension is comparatively feeble, but the quantity is abundant enough, even from a very small pair of plates, to keep a sensible current. The lowness of the tension of voltaic electricity renders the insulation of the conducting wire comparatively easy, while frictional electricity, from its great *tension* or power of overcoming resistance, passes even by the most imperfect conductors. Hence the earlier attempts in electric telegraphy, in which the machine was used, were failures—because the conducting wires could not be sufficiently insulated.

20. Faraday has calculated that a wire of platinum and one of zinc $\frac{1}{18}$th of an inch thick, immersed $\frac{5}{8}$ths of an inch in a mixture of one drop of acid to four ounces of water, will produce in three seconds as great a quantity of electricity as thirty turns of a fifty-inch plate machine. Voltaic electricity* has been compared to steam rising quietly from an open boiler, while frictional electricity is the high pressure steam of a locomotive. Lightning is the spark or discharge of electricity of very high tension.

21. The power which a pair of plates possesses of evolving electricity (16), is called its *electro-motive force*. It is the difference of *tension* between the two plates, in other words the *intensity* of the force urging forward the current when the two plates are connected by a conductor, or its *power to overcome resistance.*

22. The *intensity* of a current depends on the *energy* of the chemical action on the zinc; that is to say, on the weight of zinc dissolved per square inch of the surface of the plate.

23. The *quantity* evolved in a given time by a pair depends on the *total* amount of decomposition produced, or the weight

* Electricity produced by chemical action is called "Voltaic" or "Galvanic," from Volta and Galvani, its discoverers.

of zinc dissolved in the cell. The chemical action remains the same in force, whether the plates are large or small, so that the larger the plates the greater the weight of zinc dissolved, and therefore the greater the quantity of electricity produced.

24. The intensity of the current cannot be increased by enlarging the plates, because unless the force of the chemical action alter, the same weight of zinc will be dissolved *per square inch*, whether the plates be large or small.

25. When two or more pairs of plates are so connected that the positive metal of the first is united by a metallic conductor to the negative metal of the second, and so on, the tension is increased in direct proportion to the number of pairs. Four pairs will have four times the tension of one pair, will produce a current of fourfold intensity, capable of overcoming four times the resistance, and will diverge the electroscope four times as much.

26. Let the electro-motive force of each *pair* of this battery of four cells be such as to produce a difference in tension between its *plates* of ten, the difference between its *poles* or end plates will be four times ten, or forty.

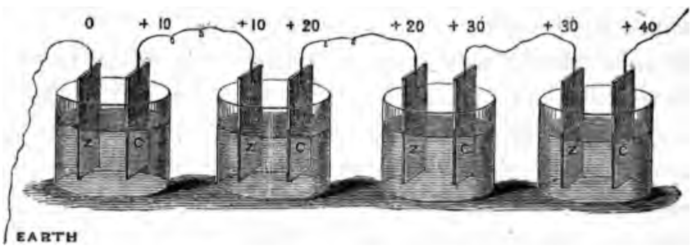
If both poles be *insulated*, the centre plates will be neutral; the zinc pole will have a − tension of 20, and the copper pole a + tension of 20.

If either pole be connected with the earth, its tension will be lost (8). But as the electro-motive force of the battery remains unaltered, the difference between its poles will still be 40, and the copper pole will have a + tension of 40 instead of 20.

Suppose a copper and zinc pair in dilute sulphuric acid; let the difference of their tensions be ten.

If the copper of the first be connected to the zinc of a second similar pair, it will communicate to it its tension.

But as the difference between the plates of the second pair is also ten, and the second zinc has a tension of ten to start with, the tension of the second copper will be 10 + 10 = 20, and so on.



27. But no greater *quantity* of electricity will be produced than with one pair—for the action in each cell is simply to urge forward the quantity arising from the oxidation or solution of the zinc of the first pair.

28. But if all the four zincs are joined together, and all the four coppers are similarly connected, so as to form, as it were, a pair of four times the surface, the *quantity* will be fourfold, but the *tension* the same as with one pair of the original size. There will be four times *more* electricity produced, but its tension or power of overcoming resistance (26) will be the same as that of one small pair, for the difference in the tension of its poles will be but 10.

29. When substances are separated into their component parts, they are said to be *decomposed*. Electricity has the power of effecting this separation. A current cannot be produced by a battery unless decomposition takes place in the cell, nor can a current pass through a solution without decomposing it.

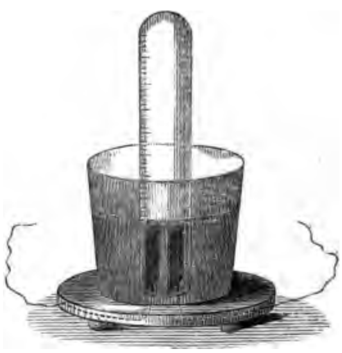
30. Sulphate of copper is a compound of sulphuric acid, water, and oxide of copper, and is called a *salt* of that metal.

Sulphuric acid is a compound of sulphur and oxygen gas. Neither sulphur nor oxygen gas can be decomposed. They are *simple substances or elements.*

Water is composed of two simple gases—hydrogen and oxygen. Oxide of copper is composed of oxygen gas and copper, both of which are simple substances.

31. When the current from a battery is made to pass through a solution of sulphate of copper contained in a separate vessel, by means of two metallic wires connected to its "poles" or terminal plates, the copper is deposited on the wire connected to the zinc, and the acid being set free, attacks the wire connected to the copper plate.

32. If the current be made to pass through water, the oxygen is separated at the wire connected to the copper, and the hydrogen at that connected to the zinc.



The amount of decomposition, and therefore the quantity of gas produced, depends on the *quantity* of electricity passing through the solution *(or electrolyte**) in a given time. A graduated glass tube to collect the gas is therefore an accu-

* Electrolyte, a substance undergoing decomposition by means of electricity.

rate measure of the *quantity* of electricity produced. The battery wires must, however, be terminated by platinum, for the oxygen combines with copper and other *oxidable* metals. This apparatus is called a voltameter.

33. A piece of zinc or iron put in a solution of sulphate of copper decomposes it by *chemical affinity*. The acid separates from the copper and dissolves the other metal, leaving metallic copper in its place, which, being precipitated, forms the so-called "mud" of the Daniell Battery.

34. When copper, pure zinc, and dilute sulphuric acid are formed into a battery, there is no action so long as the poles are disconnected from each other.

35. When the poles are united by a conductor so as to establish a *current* (18), water is *decomposed*; its oxygen unites with the zinc, forming oxide of zinc, which the acid dissolves. Its hydrogen is set free, and escapes at the surface of the copper plate in bubbles.

36. If common zinc be used, a large number of gas bubbles are given off from its own surface immediately it is placed in the acid, whether the copper be connected with it or not, and even if there be no copper plate in the liquid. Common zinc contains particles of carbon, iron, lead, and other impurities. These particles form small *local batteries*, in which the foreign substances take the place of the copper plate, causing the zinc to be eaten away in holes. More zinc is thus consumed, but less current is thrown into useful work, than when there is none of this *local action*.

37. When zinc has been frequently recast, the impurities accumulate; that at the bottom of the melting pot is the most impure. Particles of the copper deposited on the zincs (33-50) are mixed with the recast metal, in addition to the impurities previously existing.

38. When common zinc is cleaned by being dipped into

weak sulphuric acid, and then rubbed with mercury, or *amalgamated*, as the process is termed, the mercury dissolves a little zinc, which flows over and covers the foreign particles, preventing their contact with the acid. Zinc so prepared behaves like pure zinc, without local action.*

39. After a zinc and copper battery of several cells has been a short time in action, the zinc dissolved in the acid (35) begins to be deposited on the copper of some of the cells. When the poles are disconnected, this deposit is partially redissolved, especially so, if a little nitric acid be added. But nitric acid is highly objectionable, it attacks the mercury, and having formed nitrate of mercury, the sulphuric acid immediately precipitates the metal as an insoluble sulphate, disengaging the nitric acid, which again attacks the mercury until it is all gone; in this way the zinc becomes denuded of its amalgam, and is then rapidly destroyed by the sulphuric acid.

In the case of Grove's battery where very strong sulphuric acid is used, the mercury will disappear sometimes in the course of ten minutes, when the action on the zinc is so violent as to produce a heat exceeding 300 degrees, when the acid boils over.

40. The hydrogen which is given off at the copper (35) protects part of its surface from the liquid, reacting itself also upon the metal, so as to set up a reverse current, and the plate is said to be *polarized*.

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* To amalgamate zinc, clean it by dipping into dilute sulphuric acid. Place the plate in a shallow dish containing a little dilute sulphuric acid, pour a small quantity of mercury upon it, and with a piece of rag tied round the end of a stick, rub the mercury over the surface, keeping the rag well wetted with the acid. A small strip of zinc is sometimes useful to collect the mercury from the dish and place it on the plate.

41. These two causes tend to weaken the current, but they may be counteracted in part by enlarging the copper plate, giving the deposit and the gas more surface over which to spread.

42. When the acid is saturated with zinc, the current becomes very feeble, or ceases.

43. To render a battery *constant,* means must be taken to prevent this polarization, and also to prevent the deposit of any foreign metals on the surfaces of the plates.

44. The Daniell battery, which almost accomplishes this result, consists of a jar containing a plate or cylinder of amalgamated zinc, and a porous pot of half-burnt earthenware, smaller than the zinc cylinder, and fitting inside it. This "porous pot" contains a strip or cylinder of copper, and it is filled with a solution of sulphate of copper, while the outer jar is filled with dilute sulphuric acid. So long as the zinc and the copper are not connected by a conductor there is no chemical action, for the acid does not act on amalgamated or on pure zinc (34), nor the sulphate of copper on the copper; but the moment the circuit is closed, that is, as soon as a communication is established between the two metals, the zinc is strongly attacked, but no hydrogen is given off at its surface, as there is no local action. Water is decomposed, oxide of zinc is formed, which the acid dissolves, forming sulphate of zinc. The hydrogen passes to the copper, but instead of escaping at its surface, or adhering to it and *polarizing* it (40), it decomposes a portion of the sulphate of copper, precipitating copper upon the copper plate, keeping it clean and bright. The copper plates are not affected by the deposition of zinc, as in the first-named battery, until all the copper has been removed from the cell, and sulphate of zinc has leaked through the porous partition. The acid of the sulphate of copper passes to the zinc, assisting

the sulphuric acid already there to dissolve it and form sulphate of zinc. The only use of the acid originally placed in the zinc cell is to make the fluid round the zinc a better conductor; and when a large quantity of electricity is required, the sulphate of copper is also acidulated with half its bulk of strong sulphuric acid.

45. The action of the current removes one equivalent of copper (or 25½ parts) from the solution, dissolving one equivalent of zinc (or 26 parts) in the zinc compartment. Sulphate of copper contains 25½ per cent. of metal; for every 100 ounces of sulphate decomposed, 25½ ounces of copper are deposited, and 26 ounces of zinc dissolved. It is necessary to provide a constant supply of sulphate of copper, which should be placed at the upper part of the cell when energetic action is required, as it then dissolves more regularly; but at the bottom of the cell for long-continued action.

46. If there are 100 cells in the battery, and 1 ounce of sulphate of copper be decomposed in one of them, the same quantity exactly will be decomposed in each of the other 99 (leaving out of account the losses from other causes than the action of the battery) ($\frac{33}{36}$), and an equal weight of zinc will be dissolved in each cell of the battery, whether the zincs be all the same size or not. Thus, if large and small zincs be used in the same set, the small zincs will waste faster in proportion than the large ones.

47. When the acid in the zinc cell becomes saturated with zinc, the battery, though less powerful, will be more constant than when excited by acid.

Thus, a solution of sulphate of zinc may be used in the zinc cell in place of sulphuric acid, and it will not then be necessary to amalgamate the zinc plate, as there will be little or no local action (36). When continued action is required the mercury is positively injurious, because it is impossible

to prevent the sulphate of copper passing into the zinc cell (50) when the metallic copper which is deposited on the zinc-plate forms an amalgam with the zinc, which very greatly impedes the action of the battery, far more so than the black powder or "mud" deposited on unamalgamated zinc.

48. Should the water become saturated with sulphate of zinc (*i.e.*, contain as much as it can dissolve), the sulphate crystallises upon the zinc plate, stopping the action of the battery. The conducting power of solution of sulphate of zinc is greatest when diluted with an equal quantity of water. Part of the solution should, therefore, be from time to time removed, and replaced by water.

49. If the porous cell be of bad quality, containing coke or metal dust, the copper will be deposited in patches upon it. When these patches of copper touch the zinc, they form local circuits, like the particles of foreign matter contained in the zinc itself (36), wasting both sulphate of copper and zinc. When the porous cells become crusted with copper, they should at once be removed.

The zincs should never be allowed to touch the porous cells, for copper will immediately be deposited on the porous cell, so as to form a local circuit with the zinc.

50. The porous cells do not entirely prevent the mixing of the solutions; in fact, after a time much of the copper solution escapes into the zinc cell. The zinc decomposes this copper salt, and copper in a metallic form, or as a powder or mud (33), is deposited on its surface, or falls to the bottom of the cells; while the acid, set free, dissolves the zinc. This deposit weakens the action of the battery, and in some cases, where the cells or pots are very porous, as much zinc is dissolved and sulphate of copper used when the battery is idle as when it is at work. The zinc cell should be much larger than that containing the copper, in order that the sulphate

of copper which leaks through may have more liquid into which to diffuse itself, and thus become more dilute; the zinc will then act on it less rapidly. The liquid passes through the porous cell from the zinc to the copper, in virtue of a singular property, common to all porous substances when dividing dissimilar liquids, called "osmose," and it will frequently rise in the copper cell an inch or more above the level. The current aids this movement.

51. When the solution in the copper cell becomes exhausted, the hydrogen commences to decompose the sulphate of zinc which has passed through the porous partition, and to throw down zinc on the copper plates, causing "black coppers," and weakening their action very considerably.

52. In consequence of this tendency of the solutions to mix, it has been found that the porous cell is of little use for long-continued action. It may even be dispensed with, and the solutions separated by their respective weights alone. The copper solution being heavier than the zinc, the copper plate and crystals of sulphate of copper should be placed at the bottom of the cell, the zinc plate near the top. The copper solution will, however, in time, diffuse itself completely through the cell.

53. In this battery the cells should not be too much filled with crystals, for in this case the level of the copper solution is raised to the zinc plate, and the zinc reduces the copper from the solution in the form of black mud. It is a very common and a very wasteful process to put in as much sulphate as the cell will hold.

When the plates are placed vertically in this form of battery, the two metals should never face or cross each other, but the upper edge of the copper should be level with, or rather below, the lower edge of the zinc. If the zinc be below the upper edge of the copper, it will remove all the metal

from the sulphate of copper solution as far as the zinc plate reaches, and it will therefore leave none to act upon that part of the copper plate which faces the zinc. The sulphate of copper should be so placed as to dissolve only just as fast as it is used up by the action of the battery, for although its solution may be heavier than the solution of zinc in the upper part of the vessel, the two will certainly mix after a few days.

The action of zinc upon sulphate of copper is well seen by suspending a piece of the metal in a weak solution of the salt: the zinc will be covered with metallic copper in a few minutes, and in a short time the whole of the copper will be removed from the solution and replaced by zinc. By this means the copper which mixes with the zinc solution may be removed, and the zinc liquid fitted for charging fresh troughs. When water contains lime (as almost all water does), part of the sulphate of copper dissolved in it is decomposed, forming a cloudy or jelly-like scum. If a drop of acid is added to the water before the copper salt is introduced, this is prevented.

54. If the several cells of a trough leak into each other the action in the cells will be increased, but the effective current will be reduced by the formation of "short circuits." The same happens in some measure when the sides of a trough are wet, or encrusted with salts.

55. When the water has become charged with the sulphate of zinc produced by the action of the battery, crystals form on the sides of the cell; the liquid passes up between them and the sides, crystallizing again above, until at last the crystals pass over the edge, and form a kind of syphon, which draws off the liquid, especially when the trough is made of gutta-percha. Du Moncel recommends cleaning the edges of the cells with turpentine, and smearing them with a mixture of tallow and wax.

56. The zinc plates should be frequently well cleaned, as the copper deposited upon them weakens the current.

57. The coppers should also be carefully brightened before placing them in a battery. They may be cleaned by being made red hot and dipped into weak ammonia. A piece of "card," used in cotton manufactories, is the best brush for battery plates. Care must be taken that the pores of the porous cells are filled with the acid or sulphate, not with water, or their action will be considerably checked.

58. It often happens that the copper plate is eaten away near the surface of the solution; it is supposed that this is caused by the formation of nitric acid from the atmosphere, but the subject demands further investigation. The copper is frequently attacked when the supply of sulphate of copper has been exhausted.

59. Care should be taken that none of the cells be allowed to become weaker than the rest, or else the plates in the weaker cells, instead of assisting, retard the passage of the electricity generated in and transmitted across the stronger cells. Each zinc plate so circumstanced has to be assisted before the whole current can pass between it and the liquid. The current cannot pass without effecting decomposition, and thus, when all the copper salt has been expended, the sulphate of zinc remaining in the cell is decomposed, and metallic zinc deposited on the copper as a black powder (black coppers, 51). As old batteries contain weak, exhausted charges, they must never be connected in series with new ones.

60. When the plates are reversed there is not merely the contrary action of the reversed pair, but its solutions must be decomposed before the current of the rest of the battery can pass. Thus, if one pair out of four be reversed, it will nearly neutralize the effect of the other three.

61. Large and small plates should not be used in the same series. The same weight of zinc is dissolved in each cell whether small or large (46). The liquid in the small cells becomes, therefore, more quickly exhausted. From what has been said, it will appear that it is a false economy to work batteries after the zinc or the porous cells have become coated with copper, or to use cracked porous cells.

62. SAND BATTERIES.—Amalgamated zinc and copper, placed in a cell filled with pure, sharp sand, moistened with dilute sulphuric acid, form a convenient portable battery. When the battery is not in use the acid dissolves a little copper, which is again deposited on the plate when the battery is worked.

Care must be taken that the sand is quite free from iron, lime, or other impurities, and that the water is freed from lime. The so-called "solution" or dilute acid should, therefore, be mixed before it is wanted, when the lime will fall down in a white powder. Lime frequently encrusts the zinc, and spoils the battery.

There is very little room for liquid, so that, if in constant action, the sand soon becomes choked with sulphate of zinc. This can be removed by soaking the trough in water, and draining it carefully.

63. If the copper cell of a Daniell be filled with weak acid, 1 to 15 by measure, and the zinc cell with a weak solution of sulphate of zinc, a battery on the same principle as the sand is formed, which has the great advantage of giving room for the sulphate of zinc formed by the action of the current. In such a battery the zinc ought not to be amalgamated. These batteries are useful at stations where the telegraph is very seldom used, but are not fitted for constant work.

64. The batteries of Grove, Bunsen and Smee are not generally used for telegraphic purposes. In almost every case in which they have been used they have given way to Daniell.

The battery used on the South Eastern Railway by Mr. Walker, to ring the signal bells, consists of gas carbon platinised, and amalgamated zinc, with dilute sulphuric acid.

To ensure constancy of action, the jar should be considerably deeper than the plates, so as to contain plenty of liquid. The plates are placed in the upper part of the jar, so that as the solution becomes saturated with zinc it falls to the bottom, leaving the lighter acid to act on the plates. A percha slipper containing mercury is attached to the zincs.

Care must be taken to keep porous cells or troughs fitted with porous plates moist after they have been used, or the sulphate of zinc contained in the pores will crystallize and destroy the porous ware, by an action similar to that of frost.

65. Where a constant current is required, as for signal instruments, or Morse circuits worked from one battery, the Belgian globe reservoirs or feeding bottles are very convenient. A smooth-necked, wide-mouthed bottle, sufficiently large to contain enough for six months' consumption, is filled with sulphate of copper in crystals and a saturated solution; a cork and glass tube are fitted airtight, the bottle is reversed, and the tube placed in the copper cell. The liquids mix through the tube until a layer of solution of copper, of the same strength as that remaining in the bottle, is formed in the cell, extending upwards only as high as the lower end of the glass tube; the distance at which the tube is placed from the bottom of the cell thus regulates the depth of the stratum of sulphate. The action is much more regular than if the crystals were placed in the copper cell.

66. In order to ascertain the working condition of a battery, it should be tested with a detector wound with thick wire ("Quantity detector" 114), or with an ordinary detector, whose sensitiveness is reduced by a "shunt," so as to allow but a very small portion of the current to flow through its coils. One cell in good order will give as large a deflection as 100 of the same kind, but if any one of the 100 is defective, the deflection will be less than that given by a single good cell, and one bad cell will spoil the entire set (59). First find, by testing, which trough is faulty, and then try the cells one by one.

67. SECONDARY BATTERIES.—When a number of pairs of plates of the same metal, as lead or platinum, are arranged in series as a battery, with dilute acid, if a current is made to pass through it, its plates are *polarized;* so that, on breaking contact, a transient *reversed* current is obtained.

The water in its cells is decomposed, the oxygen and hydrogen are given off on the surfaces of the opposite plates in each cell (40), and with the lead plates the peroxide of lead is formed: these *excite* the battery for a short period.

This arrangement is called a "secondary" battery; and it is the formation of a similar pair which sometimes after testing buried or submerged wires causes a temporary current in a reversed direction to the testing current.

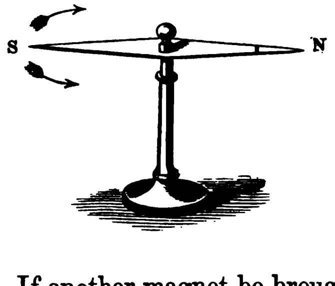
It has been proposed to include such a series of plates in a submarine circuit, in order to obtain a transient reversed current during the pauses of signalling, and they have been used in Varley's translating apparatus for a similar purpose.

PART II.

MAGNETISM; AND THE CONNEXION BETWEEN MAGNETISM AND ELECTRICITY.

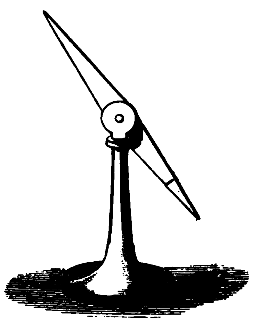
68. Pieces of iron or steel which have long remained in a north and south position, or have been subjected to certain processes, attain the power of attraction and repulsion, and are called *magnets*. Some of the ores of iron possess the same property, and are called *natural magnets* or *loadstones*.

69. If a magnet be balanced on a pivot so as to move horizontally, as in the mariner's compass, it will place itself in the *magnetic meridian;* that is, point *north and south*. The end which points to the north is called the north pole; that which points to the south, the south pole.



If another magnet be brought near it, the similar poles will be found to repel, the dissimilar poles to attract one another. That is, the north pole of one will repel the north pole of the other, and attract the south pole, and *vice versa*. But if a

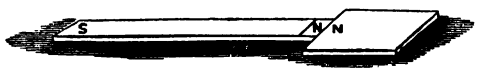
piece of iron or an *unmagnetized* steel bar be used, either pole will be attracted, and no repulsion whatever will occur.



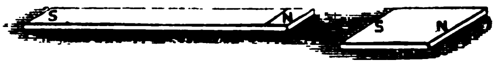
70. Balance a steel bar on a horizontal axis so that it may move vertically, it will remain at rest in any position. Magnetize it, and the north end will appear to have become heavier, or will *dip*, unless it be placed east and west, when the magnetic force will simply produce pressure on the pivot; for the manner in which it is pivoted prevents its moving when in this position.

71. If a magnetic bar be tested, it will be found that its force resides principally at the ends or *poles*, and that it decreases to nothing at the centre of the length of the bar. If a magnet be broken, each piece will become a perfect magnet; but if the pieces are placed closely together again, the intermediate poles will disappear and the magnet will have only two poles as at first.

72. When a piece of iron or steel is placed near, or in contact with a magnet, it acquires magnetic properties by *induction*. If the two *touch* each other the iron will have



the same polarity as the end or pole of the magnet to which it adheres, and will become, as it were, a prolongation of the pole. If they be *removed a short distance* from one another,



the portion of the iron next the magnet will be found to have acquired an *opposite* polarity, and the most distant end a similar polarity to the nearest pole of the magnet.

73. Nearly all traces of magnetism in the iron cease as soon as it is removed from the influence of the magnet, for *iron* cannot retain magnetism, or cannot be permanently magnetized, when soft and pure.

Steel, on the other hand, is not attracted as forcibly as iron; it acquires magnetism with greater difficulty, but retains it more or less permanently. The harder the steel, and the longer the bar, the more permanently will it retain its magnetism.

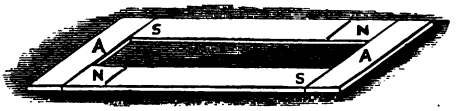
A straight bar is called a bar magnet; the small bar magnets used in telegraph instruments and ships' compasses are called *needles*, and when a bar is bent, so as to bring its two ends or *poles* near one another, it is called a *horse-shoe* magnet.

A *compound* magnet consists of two or more bar or horse-shoe magnets placed side by side, with their similar poles in contact. Care must be taken that all the bars are equal in power, or the feebler will be weakened, or even reversed, by the stronger.

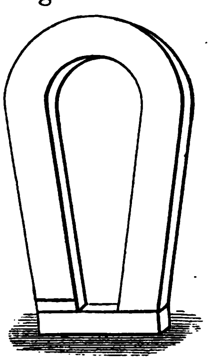
74. The processes for magnetizing steel bars, or forming artificial magnets, are founded on the principle that a north pole induces a south pole, and *vice versa* (69). If the north pole of a weak magnet be applied to the north pole of a stronger magnet, its polarity will first be destroyed (the bar will be *demagnetized*) and then *reversed*, or the north will become a south pole.

75. The earth itself acts as a magnet, and, consequently, if

magnetized bars are laid aside without regard to the direction in which their poles are placed, they become *demagnetized* by the action of the earth's magnetism. But needles hung horizontally, as compass needles, always take up the right position for retaining their power. The poles which attract each other tend to preserve each others magnetism, those which repel tend to destroy it.



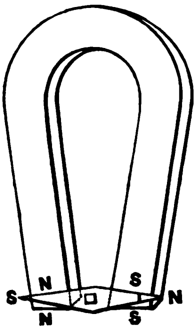
To prevent this loss of power *armatures* or *keepers* of soft iron are used, applied to or placed across the poles. When out of use bar magnets should be placed as in the figure, where A A are the armatures and S N N S the magnets.



The armatures of horse-shoe magnets are applied thus. They may with advantage be weighted, and if the weight is gradually increased, taking care never to make it sufficient to tear the keeper away, (which would weaken the magnet,) the strength of the magnet will be increased also.

The armature should always be slid off, never forcibly detached.

76. Magnetism acts through all substances not themselves capable of being magnetized. A compass in a brass or wood box is as easily affected as if it were not so enclosed; but if shut in an iron box, a magnet outside would act on it indirectly only, through the magnetism induced in the iron of which the box was composed.

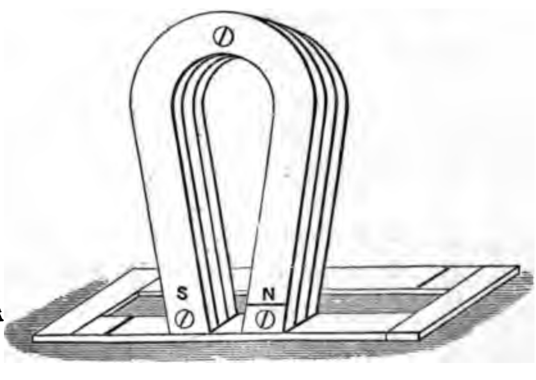


77. To magnetize a small bar, such as the *needle* of a telegraph instrument, all that is necessary is to lay it across the poles of a horse-shoe magnet, the end required to be the north pole on the south pole of the horse-shoe, and *vice versa*, rubbing them together for a minute in the direction of the needle's length.

In England the north end of a magnet is marked by the letter N, or by a line filed across it.

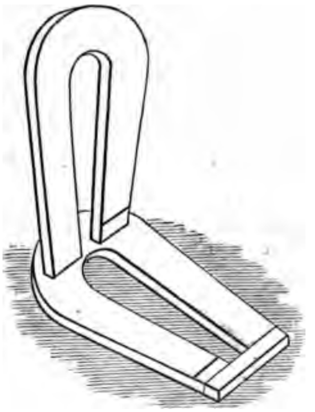
To magnetize a pair of bars of several inches in length, place them flat on a table,

A



A′

as in the figure, between two pieces of soft iron as armatures A A′. Place the horse-shoe magnet S N on one end of either of the bars, with its *north* pole upon that extremity of the bar which is required to become a *south* pole. Slide the horse-shoe along the bar, carrying it round the whole system several times, stopping finally in the centre of one of the bars as shown in the figure. Repeat the process on the other face of the bars.



A horse-shoe may be magnetized in a similar manner, commencing at one end of the poles, sliding the magnet round the horse-shoe and its armature, finally stopping at the centre of the curve of the horse-shoe.

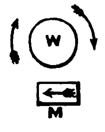
When a bar is carelessly magnetized it may acquire one pole or more in addition to those at its ends, when it will be found not to act as strongly as it should do.

CONNEXION OF ELECTRICITY WITH MAGNETISM. ELECTRO-MAGNETISM.

78. A wire through which a current is passing (a conducting wire) attracts iron filings. Two parallel conducting wires will attract each other if the current flows in the same direction in both, and repel if it flows in opposite directions.

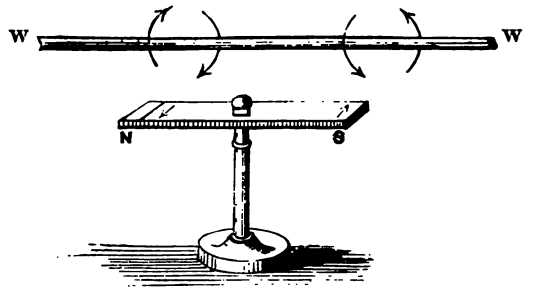
The wire if straight possesses no polarity, but its force is distributed equally throughout its entire length.

79. A conducting wire has also an action upon a magnet, they would revolve round one another if free to move; the opposite poles of the magnet in contrary directions.



Thus, if M be one pole of a magnet and W a section or slice of a conducting wire, if W is fixed and M free to move in all directions, M will revolve round W.

But if M is fixed on a vertical axis, so that it can move in the horizontal direction only, it will move from right to left; and as the other pole of the magnet would tend to revolve in the contrary direction, it will move from left to right.



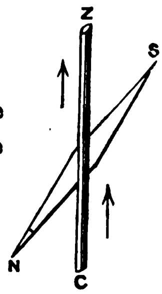
Thus, if the two poles N S of a compass needle placed under a conducting wire W W′ tend when considered separately to revolve in the directions shown by the arrows, the needle, being capable of motion in the horizontal direction only, will take up a position at right angles to the wire: the end N being urged *towards* and S *from* the reader.

80. The following illustration, contrived by Ampere, is useful as an aid in determining in what direction a current will move a magnet.

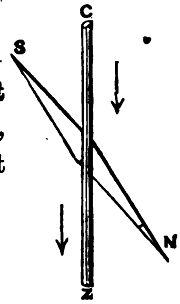
Suppose one's feet to be connected to the copper, and one's head to the zinc pole of a battery, the current would flow upwards through the body. If a magnetized needle, suspended vertically, as in a needle instrument, be held before the breast, the north pole of that needle would be moved to the left hand, towards a position at right angles to the body. If the needle were held at the back, or if the direction of the current were reversed, the direction in which the needle would be moved would also be reversed.

In these diagrams the body of the person holding the needle is represented by the wire Z C, and the needle by S N.

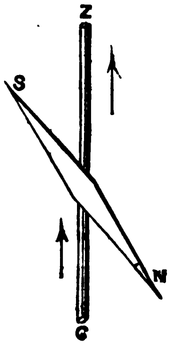
Thus: the wire in front of the needle.



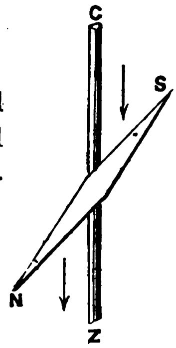
The wire in front of the needle, and the current reversed

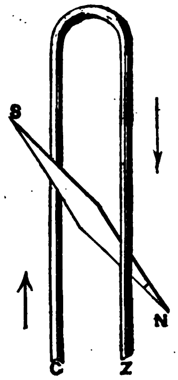


The wire behind the needle



The wire behind the needle, and the current reversed.

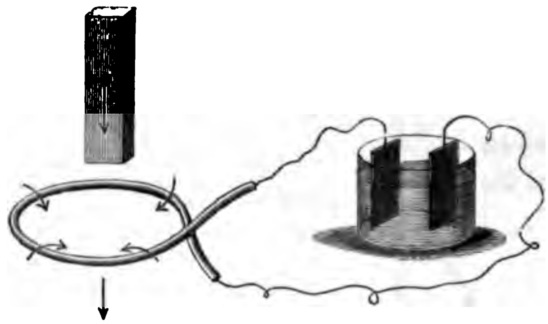




It will be perceived, that when the wire is bent round the needle thus, its two halves act similarly on the needle, and the effect is doubled. The current ascends *behind* the needle, as in the third illustration, and descends in *front* of it, as in the second.

If the wire be bent a second time in the same direction round the needle, its effect will be again doubled, and

by a further increase in the number of turns a corresponding increase in force will be obtained.



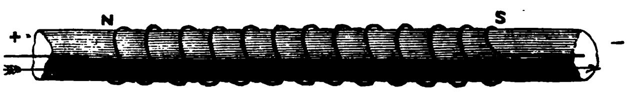
If the wire is covered with an insulator, as silk or cotton, so as to compel the current to traverse its entire length, and is formed into a ring or a spiral, if one pole of a magnet be presented to the centre of the ring, the tendency to rotate will cause the magnet to be drawn into or expelled from the ring according to the direction of the force of rotation.

The ring and the spiral will thus appear to have an attractive force or polarity while the current passes; they will place themselves north and south, and act like magnets.

If a spiral be wound *right*-handed, like an ordinary screw, that end of the wire which is connected to the

+ or copper pole of the battery will be a south pole.

If the spiral be *left*-handed, the + end of the wire will be a north pole.



A bobbin or coil frame filled with covered wire is simply a number of spirals wound over each other; so that if a magnet be pivoted in the centre of a coil as in a needle instrument or galvanometer, its poles will be attracted and repelled by the poles of the spiral, or, more correctly, the force of rotation will cause a motion similar to that of attraction and repulsion, or *deflect* the needle.

81. If the wire be wound upon a bar of iron, the iron becomes magnetic, and the force of the coil and iron together is very much greater than that of the coil without the iron *core*. It is called an *electro-magnet*, and its polarity depends on the direction of the spirals.

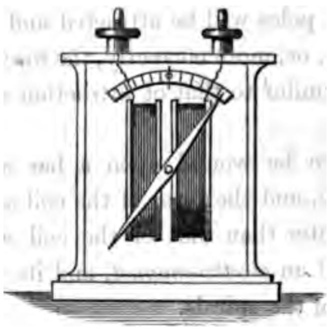
If the iron be very soft and pure, it loses its magnetism immediately the current ceases; but if impure, or if hardened by hammering or turning, it retains a certain amount of *residuary* magnetism.

When the core for the electro-magnet has been formed, it should be made redhot, and very carefully annealed by the fire being allowed to die out.

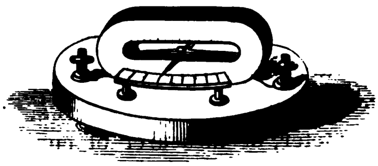
82. A galvanometer, or measurer of currents, consists of a magnetized needle placed in the centre of a hollow frame filled with covered wire. The *degree* to which the needle is moved shows the *quantity* of electricity passing through the coils; when the deflection of the needle is increased by adding more cells to the battery, it is because a larger quantity is, as it were, *forced* through the wire by the increased tension. The *direction* in which the needle is moved shows the *direction* in which the current is flowing.

The *needle instrument* is simply a vertical galvanometer fitted with an apparatus for placing a battery in circuit and *reversing* the current or changing the direction in which it flows.

Two kinds of galvanometers are used in the service, the "detector," in which the needle hangs vertically, and one in



which the needle is suspended, or poised on a point like that of a mariner's compass. The latter form is much more sensi-



tive than the former, because the friction of the pivots is less, and the needle is kept in its position by the directive action of the earth only; that is, by its tendency to stand north and south. In using the horizontal galvanometer it must be carefully levelled, and as the needle will point to the north the case must be turned so as to bring the coils into their proper position, and the needle to the zero of the scale. The vertical galvanometer is more easy to use, as it needs no adjustment, for the north end of the inner needle is always made sufficiently heavy to keep it upright.

84. In both these instruments the angle through which

the needle is moved, that is, the number of degrees through which it passes, is not an accurate measure of the strength of the current when the deflection exceeds 20; for the further the needle moves from a position parallel to the wires of the coil, the more nearly does it approach a right angle, where the effect is null; so that the action of the current upon it becomes less and less powerful as the deviation increases.

This may be partially remedied by winding the coil so that the wires radiate from the centre.

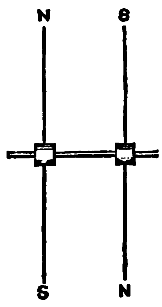
In a well-made vertical detector, the values of the degrees marked on the dial were found to be *nearly* correct to 30°, and

40°	were equal to	44	parts of electricity.
50°	"	65	"
55°	"	78	"
60°	"	93	"
65°	"	130	"

But the value of the ordinary degrees would not be alike for any two galvanometers, each must be graduated by actual trial.

85. The sensitiveness of the vertical "detector" may be much increased by lessening the weight of the lower or north end of the inner needle, but in this case the instrument must be so placed that its dial faces the north or south, or the *dip* (70) will cause the needle to hang on one side. Whenever the needle of a needle instrument will not hang vertically, except the case is in one particular position, it is because of the dip. Needles properly balanced for this country will be found wrong if sent to Australia, for there the south end will dip, or appear the heavier.

86. Both the horizontal and vertical galvanometer may be greatly increased in sensitiveness by making the outer needle, or pointer, a magnet, placing its poles in a contrary direction

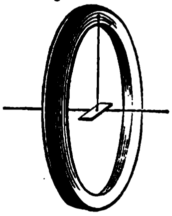


to those of the inner magnet. If the two are exactly equal in power, the pair will have no tendency to point to the north, because the directive action of one will be counteracted by the equal and opposite action of the other, and the pair will be what is termed "astatic." In a horizontal galvanometer the inner needle should, in practice, be a little stronger than the outer, so that the pair may have a slight tendency to point north and south sufficient to enable it to regain its position after having been deflected. But the more nearly alike the two needles are in power, the greater the delicacy of the galvanometer. A vertical galvanometer, laid on its back and placed N. and S., will be very much more easily deflected than when standing upright.

87. The force with which the current acts on a vertical galvanometer depends on the strength of the magnetism of the needle, which is constantly decreasing (75), and this force varies very much in an astatic arrangement from alterations in the *relative* strength of the two needles. But if one needle only be employed in a horizontal galvanometer, these sources of error are avoided. The needle is kept in place by its *directive force*, or tendency to point north and south, and the feebler the magnetism the less resistance will it offer to being moved by the current, while, on the other hand, the current acts with less force on a feeble magnet. The two thus counteract one another, and the instrument is constant in its indications, though, of course, less sensitive than if "astatic." Nor will it have a tendency to lose its magnetism (75).

88. In the *sine* galvanometer, the source of error mentioned in paragraph 84 is avoided. The coils are made movable, so as to *follow the needle* as it is deflected, until it

again points to the zero of the graduation, that is, stands parallel with the wires. Thus the needle is constantly in the same position with regard to the wire, and the current has always the same *degree of leverage* upon it. The sine of the angle through which the coils are moved before the force of the current is exactly balanced by the weight or directive power of the needle, is the measure of the quantity of electricity in action.



89. The *tangent* galvanometer consists of a ring having a groove on its edge filled with wire. The needle is hung precisely in the centre of the ring, and must not be longer than one-sixth of its diameter—a half-inch needle requiring a three-inch ring. The needle is deflected with a force varying as the *tangent* of the number of degrees through which it moves. Owing to the great distance of the coil from the needle, this instrument has very little sensitiveness as compared with the others before mentioned; a modification by M. Gaugain is, however, a very useful instrument. (See note.)

90. Electro-magnets (81) are generally made in the horse-shoe form: that is, two bobbins are formed by fixing ivory or brass ends upon *cores* of the purest and softest iron; these bobbins are filled with covered wire and fixed upon a connecting bar of iron.

If the wire is wound upon a metal bobbin, into which the iron core is made to slip, the bobbin must be slit from end to end, or a current will be *induced* in the metal by the magnetization of the iron, which will prevent its gaining or

losing its power as quickly as it would otherwise do, and thus interfere with the rapidity of its action.

The current would in this case be somewhat further removed from the iron, and would act less powerfully upon it. The wire should therefore be wound upon the iron itself.

91. Great care must be taken to preserve the insulation of the several turns of the wire, and especially to prevent metal filings from sticking to the covering, for they will pierce the silk and connect one turn with another, forming a "short circuit."

92. The efficiency of the galvanometer and the electromagnet depends upon the same laws.

The effect of the current is multiplied by the number of the turns of wire in the coil.

It is lessened by an increase in the distance from the magnet or core, each turn acting less powerfully than the one beneath it.

In an *electro-magnet*, the diminution of the effect of the current by increase of distance is not so great when the diameter of the coil is small compared with its length, so that a long electro-magnet is comparatively more effective than a short one.

The current itself is enfeebled by each addition to the length of the coil, because of its increased *resistance* (105); and this will be more felt when the coil is placed on a short circuit than when the line wire has itself considerable resistance (121), because of the difference in the proportion between the resistances of the coil and the line.

93. When a line wire is very long, the current will necessarily be feeble (105), and the coil should consist of *fine* wire, which occupies very little space, and allows very many layers to be wound on without increasing the distance from the

core or the needle too much, while its resistance bears too small a proportion to that of the rest of the circuit to reduce the strength of the current materially (121). Very delicate galvanometers have as many as thirty thousand turns of wire in their coils.

94. But when the line is short, each layer of fine wire would decrease the useful effect by adding to the resistance of the circuit more than would be made up by the multiplying effect of the increased number of turns, for a few layers would double the resistance of the circuit.

A thicker wire will not materially enfeeble the current, and though it takes more room, yet a sufficient number of turns may be employed without exceeding the distance at which the current acts with advantage.

95. Electricity and magnetism mutually reproduce one another. Not only can iron be magnetized by a current (81), but a current can be obtained from a magnet. If a piece of soft iron be wrapped with insulated wire, and be magnetized by a permanent magnet, a current will be set up in the wire whenever the magnetic state of the iron is altered by its being made to approach or recede from the permanent magnet. The current is but momentary; it exists only during the time the magnetic change is taking place; and the direction of the current produced by the *cessation* of magnetism will be the reverse of that set up by its production. The more rapidly the magnetic change is brought about—that is, the more promptly the soft iron armature is placed in contact with or detached from the magnet—the greater will be the tension of the current.

96. The "magneto-machine" for ringing bells consists of a large magnet, whose armature is wound with wire. When the armature is forcibly detached by the lever a current

passes through the wire; and another, but in a reverse direction, when the armature is replaced. The great advantage of this apparatus is, that the reverse current detaches the armature of the electro-magnet of the alarum and prevents its running down.

PART III.

RESISTANCE AND THE LAWS OF THE CURRENT.

97. When the poles of a battery are connected together by a conductor, so as to form a *circuit*, the electricity flows as a *current* from the zinc to the copper plate through the battery itself; and from the positive, or copper, to the negative, or zinc, pole through the conductor.

98. A telegraph *circuit* consists of the battery, the instruments, and a conductor to unite the two poles of the battery, composed of the line wire, and the earth instead of a return wire. In the case of local circuits not extending beyond the house, a return wire is used instead of the earth.

99. Owing to the rapidity with which the electric force travels in the form of a current, when not influenced by induction, any effect which can be produced at hand can be produced at a distance at the same instant of time; subject to a diminution of force dependent on the *resistances* of the circuit, and the losses from bad insulation, which diminish the quantity of electricity or current before its arrival at the distant end, and thus weaken the signal : for all telegraphic signals, including the deflection of the galvanometer, depend

upon the *quantity* of electricity passing through the receiving apparatus in a given time, not upon the *tension* of the received current.

If the tension of the battery is increased, it is with the view of enabling the current more readily to overcome the resistance of the circuit, so that more electricity may pass in a *given time.* Thus, when the deflection of a galvanometer is increased by an increase in the number of cells of the battery, it is because a greater *quantity* is, as it were, *forced* through the wire (82).

100. *Resistance* is the obstacle offered to the current by the bodies through which it is made to pass, and is the opposite or converse of their conducting power. When resistance is infinite it becomes *insulation.*

101. All bodies do not conduct equally well; each has a certain *specific resistance,* that is, a resistance peculiar to itself (10).

102. The resistance of a solid conductor, such as a telegraph wire, is in direct proportion to its length, and in the inverse proportion of its weight per mile. Ten miles of wire offer tenfold the resistance of a single mile of the same wire.

The resistance lessens as the size of the wire increases, in the ratio of the square of its diameter. It will take four wires $\frac{1}{8}$ of an inch thick to make up the substance of one $\frac{1}{4}$ of an inch thick, and the $\frac{1}{4}$ inch wire will offer only a quarter of the resistance of that of $\frac{1}{8}$ diameter, the lengths being equal. Four miles of the thick wire will conduct as readily as one mile of the thin.

If the thickness of the wire be increased to $\frac{3}{8}$ inch, nine miles will offer the same resistance as one mile of the thin conducting wire, nine being the square of three.

103. Hence the advantage of a thick line wire. If the battery and instrument offer a comparatively feeble resistance,

as good a signal can be produced at nine miles distance with a wire $\frac{3}{8}$ inch diameter, as at one mile with a wire only $\frac{1}{8}$ thick.

104. Whatever be the origin of an electric current, its power can be measured by the amount of work it performs. In order to ascertain this, it is most convenient to use a galvanometer. The force of the current depends on two things, the electro-motive force which sets the current in circulation, and the resistance the electricity has to surmount.

105. If a constant battery be connected with a galvanometer by wires of various thicknesses and lengths, it will be found that the greater the resistance introduced into the circuit, the less the needle is deviated, showing that the current is enfeebled, and that the deflection is proportional to the total resistance. If two wires introduced in turn into the circuit produce the same deflection, their resistances are equal.

106. It is convenient to fix an unit or standard to which all resistances can be compared. One mile of the wire used for tunnels and underground work, No. 16 copper, is the "*Varley unit*" or standard adopted by the Electric Telegraph Company. If, then, a mile of this wire be placed in circuit, and the deviation of the needle noted, we can find by trial how much copper coil wire, or fine iron wire (the resistance of which is greater than copper), must be used to give the same deflection with the same battery and galvanometer. This wire, if wound on a bobbin and preserved, becomes our mile measure. If a number of bobbins be filled with fine wire equal in resistance to various lengths of the No. 16 wire, we obtain a *rheostat*, or set of resistance coils.*

* German silver wire is now generally used for resistance coils, because its conductivity is but little affected by change of temperature when compared with pure copper.

107. By comparing the resistances of iron wire with this standard, it will be found that—

No 16 copper being	1·000
No. 8 iron wire (the usual size) is nearly ...	·509
No 4 do. do. do. ...	·293

That is, one mile of No. 8 iron is equal in resistance to rather more than half a mile of No. 16 copper, or half an unit. If the wire is stretched, it will increase in resistance. Soft, or annealed wire conducts better than hard. The specific resistance of copper or iron wire varies very much. In the Malta and Alexandria cable, the different portions of the copper conductor varied from 90 to 74, pure copper being 100 (silver 92).

The resistance of a pair of ordinary needle instrument coils equals 20 miles of ordinary line wire, or 10 "units." Thus, a circuit of 20 miles of line with six instruments has the same resistance as one of 100 miles with only two instruments; and supposing each equally well insulated, a battery will give equally strong signals on either wire.

108. All experiments for resistance can be as well performed with an artificial line made up of resistance coils (106) as on the actual telegraph, provided we do not require to take into account loss from bad insulation.

109. The battery itself offers a resistance depending on the conducting power of the liquids with which it is charged, and that of the porous division which separates them. It is also modified by the size of the plates, for the larger the plates the greater the area of the liquid and the less its resistance; and by their distance from each other, for the closer they are placed the shorter is the liquid conductor. As liquids are bad conductors (110), the size and distance of

the plates have a very great influence on the resistance of the cell.

The material of the porous division is generally a non-conductor, so that the current passes entirely by its pores.

The introduction of porous divisions therefore increases the resistance of the cell, by decreasing the area of the liquid.

110. Saline and acid solutions, though the best of liquid (non-metallic) conductors, offer enormously more resistance than metals, thus :—

If the resistance of copper be ...	1,
That of 1 part sulphuric acid to 11 of water will be	1 million,
That of a saturated solution of sulphate of zinc will be	16 millions,
That of a saturated solution of sulphate of zinc diluted with equal parts of water will be	14 millions,
That of a saturated solution of sulphate of copper will be	17 millions,
And of distilled water	6,754 millions.

The resistance of liquids increases with cold, consequently batteries do not work well unless kept moderately warm.

111. As a battery is merely a number of cells connected in series, its resistance increases in proportion to the number of cells composing it.

112. The electro-motive force also increases in the same proportion. Ten cells will have tenfold the electro-motive force and tension of one cell (25), and ten times the resistance.

113. The current through the circuit (98) will equal the tension or electro-motive force (21), divided by the resistance

of the battery and conducting wire (including of course, the apparatus for signalling) forming the circuit.

Call the electro-motive force ... ... E
" battery resistance ... ... R
" apparatus and line resistance L
and the current C

Then C will equal $\frac{E.}{R + L.}$ This is one of "Ohm's laws."

The less the resistance (R + L), the more current will pass in a given time (99); or, in other words, the greater will be its quantity.

114. Take a set of batteries, say 24 small cells, whose resistance is, say 6 units, with an electro-motive force of 1 for each cell, that is, 24 for the 24 cells.

Connect it to a *quantity* detector, the coils of which are formed of No. 16 wire, only 3 or 4 yards in length, which will offer no resistance, or next to none, to the current. The current will be $\frac{E}{R}$ that is $\frac{24}{6} = 4$.

Take off half the battery $\frac{\frac{1}{2}E}{\frac{1}{2}R}$ will be $\frac{12}{3} = 4$.

Leave only one cell $\frac{\frac{1}{24}E}{\frac{1}{24}R}$ will be $\frac{1}{\frac{1}{4}}$ or still 4.

115. Thus, with a thick wire detector, a single cell, if not producing a greater quantity of electricity than can be carried off freely by the wire, will give as large a deflection as any number that may be connected in circuit. For *each cell brings its own resistance with it*, and the increased intensity is solely occupied in overcoming the increased resistance. If, then, the *resistance* of a circuit be increased in the same proportion as the number of cells in the series, the deflection will remain unaltered.

116. Test the same battery with a fine wire detector, whose *resistance* (" r ") equals, say 6 units, and is therefore considerable.

With 24 cells $\dfrac{E}{R+r}$ or $\dfrac{24}{6+6}$ = 2, force of the current.

With 12 " $\dfrac{\frac{1}{2}E}{\frac{1}{2}R+r}$ or $\dfrac{12}{3+6}$ = $1\frac{1}{3}$ or 1·33.

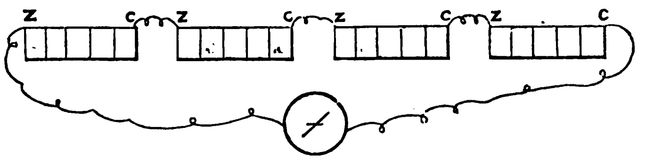
With 6 " $\dfrac{\frac{1}{4}E}{\frac{1}{4}R+r}$ or $\dfrac{6}{1\frac{1}{2}+6}$ = $\dfrac{6}{7\frac{1}{2}}$ = $\frac{4}{5}$ or 0·80.

Here the deflection increases with the number of cells, but not exactly in proportion to the number added; for each cell *brings its own resistance with it, and thus lengthens the circuit.*

After a certain limit the deflection would not increase at all, even if the detector were so arranged as to be able to register it.

117. Connect the same set of batteries to a line, the resistance of which, inclusive of that of the galvanometer, is one unit or mile.

BATTERY SIX MILES.

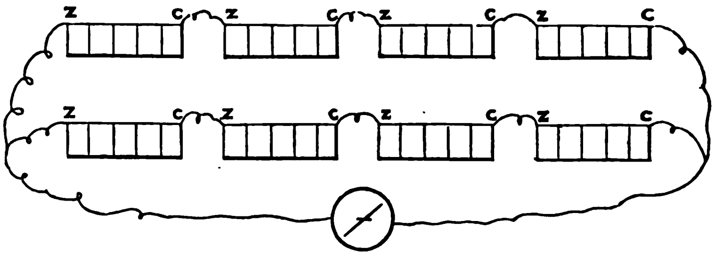


LINE AND DETECTOR ONE MILE.

Here the current or deflection will be $\dfrac{24}{6+1}$ = 3·42.

118. " Double the quantity " by placing a similar set by its side, connecting the two terminal zincs together, and the two terminal coppers thus :—

BATTERY THREE MILES.



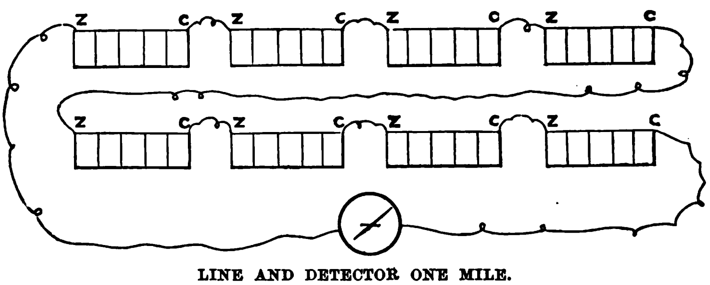
LINE AND DETECTOR ONE MILE.

The electro-motive force or tension of the battery will be the same as with the single set, while its resistance will be halved, because the size of the plates is doubled.

Here the deflection will be $\frac{24}{3+1} = 6$, or nearly double.

119. Connect the two sets for "intensity," thus :—

BATTERY TWELVE MILES.



LINE AND DETECTOR ONE MILE.

The electro-motive force will be doubled, but the battery resistance will also be doubled, and

The deflection will be $\frac{48}{12+1} = 3{\cdot}7$,

or only $\frac{3}{10}$ greater than with half the number of cells, for the extra number of cells are almost entirely employed in overcoming the resistance they have brought with them.

120. Connect the batteries to a wire of 100 units.

With 24 cells the current will be $\frac{24}{6+100} = \cdot 226$.

With two sets of 24 cells arranged for "quantity" (118)

$\frac{24}{3+100} = \cdot 233$, nearly the same as with one set.

And with two sets, arranged for "intensity" (119)

$$\frac{48}{12+100} = \cdot 428,$$

or nearly double the effect of half the number of cells.

121. Thus, the *greater* the resistance of the *line*, the *less*, proportionally, is the effect of the resistance of the *battery*; and the *less* the resistance of the *line*, the *greater* the effect of the resistance of the battery.

122. On a short line, or a badly insulated long line, the size of the plates may be increased with advantage, for the resistance being less, the battery "works the harder," and is sooner exhausted. There must be sufficient tension to *force* a current to the distant end, and sufficient quantity to supply all the leaks by the way.

On a long circuit there is little or no advantage in increasing the size of the plates, *if the line be well insulated*, but great advantage up to a certain limit in increasing their number.

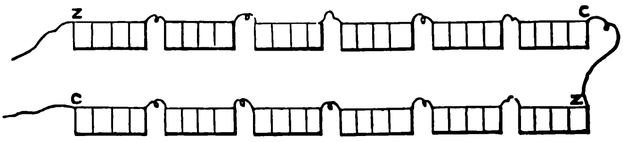
123. It sometimes happens that a supply of large cells, or "quantity" batteries, is not at hand for a faulty line, or a local circuit. The following calculation will show how to produce the greatest possible effect with a given number of equal small batteries for a temporary purpose.

Suppose the line be 6 units:

The number of cells 120, in 12 troughs of 10 cells:

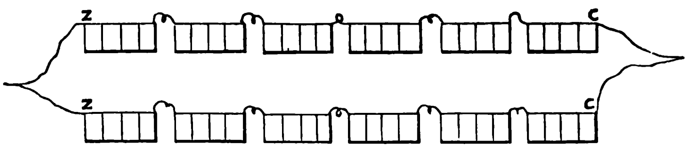
The resistance of each trough 2 units:

The electro-motive force of each trough 10°.

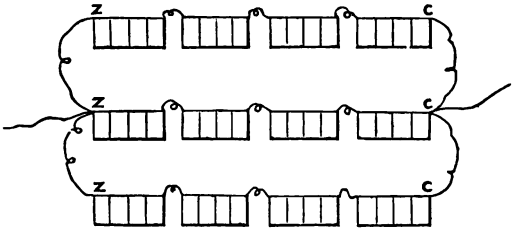


1. If connected in single series or for "intensity" (119)
   The electro-motive force will be $12 \times 10 = 120 = E$.
   The resistance of the batteries $12 \times 2 = 24 = R$.
   The resistance of the line $6 = r$

$\frac{E}{R+r}$, or the electro-motive force divided by the total resistance, gives $\frac{120}{30} = 4$ current.



2. If connected in two series of 6 troughs each,
   The electro-motive force will be $6 \times 10 = 60$.
   The resistance of the batteries $\frac{24}{2 \times 2} = 6$.
   The resistance of the line 6.
   And the current in circuit $\frac{60}{12} = 5°$



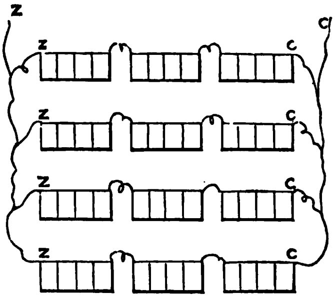
3. If connected in 3 sets of 4 troughs.

Electro-motive force $4 \times 10 = 40$.

Resistance of batteries $\frac{24}{3 \times 3} = 2{\cdot}6$.

Do. of line $6{\cdot}0$.

The current in circuit $\frac{40}{8{\cdot}6} = 4{\cdot}6$.



4. If connected in 4 sets of 3 troughs.

Electro-motive force $3 \times 10 = 30$.

Resistance of batteries $\frac{24}{4 \times 4} = 1{\cdot}5$.

Do. of line $6{\cdot}0$.

And $\frac{30}{7{\cdot}5} = 4{\cdot}0$, the current in circuit.

The greatest effect, then, of a given number of cells is produced when they are so arranged that the battery resistance equals that of the line, as in No. 2; and consequently, when a battery is placed on that line which is best adapted to it, the current it will give is exactly one-half of that which it gives when on short circuit, or when the resistance of the *line* is nothing.

124. Theoretically, then, in a well insulated circuit, not subject to leakages or faults, the maximum effect of a certain given surface of zinc plate is attained when it is divided into

so many pairs that the resistance of the battery shall equal that of the line. It has been argued from this, that the plates ordinarily used may be reduced in size with economy.

For a single experiment, such as testing a tunnel, a battery of small plates constructed on this principle is useful; not so for continued use on a circuit.

Causes which affect the constancy of a battery, such as the fouling of the plates, polarization, &c., &c. (40), have a greater effect on the small pairs, because they are spread over a small surface, while, if the plates were doubled in size, the deposit or the gas would have double the space to cover (41), and would do less harm.

125. In practice, batteries should have considerably less resistance than that of the line, in order that faults and leakages may not affect the signals seriously. When a fault arises, or wet weather comes on, the action of the battery is increased, because the resistance of the circuit is lessened (157), and there is more current flowing out to line. The plates are worked harder, more zinc is dissolved, and more acid or sulphate of copper used up in each cell, and in consequence the current fails much more rapidly than when the resistance of the line is of its proper amount.

THE EARTH.

126. Gavarret gives the following explanation of the manner in which the earth acts when forming part of a circuit:

"The poles of a battery, when disconnected, have equal
" and contrary tensions.

"When insulated conductors are placed in contact with "them, they themselves become the poles of the battery, the "battery having furnished a current sufficient to charge "them, but not of *sufficient duration* to move a galvanometer "needle.

"If the conductors are enlarged, the time occupied in "charging them will increase, until, as they are still further "enlarged, a limit will be reached at which the flow of elec-"tricity into them *will last long enough* to affect the galva-"nometer; and when the conductors become infinitely long or "infinitely large, the time occupied in charging them also "becomes infinite, or, in other words, the current will pass "precisely as if the poles were connected.

"Thus, when the extremities of a circuit are connected to "the earth, which is an infinitely large conductor, their respec-"tive tensions are diffused in all directions without producing "any appreciable tension in the earth itself, so that the current "will continue to flow." (Télégraphie Électrique, page 35).

127. The earth acts as an ordinary conductor, and opposes some resistance to this diffusion.

When a layer of soil placed in a box is compared with a similar layer forming part of the earth's surface, it is found that the isolated portion offers the greater resistance. Its resistance follows the same laws as that of any other substance, depending on its dryness or dampness, its nature, and its length and section.

128. If two earth-plates be buried in the soil, the resistance of the portion included between them does not vary in the ratio of their distance, as it would if the portion were enclosed in a box. Blavier gives the following results, which were obtained by Matteuci. The size of the plates being the same in each case.

	Resistance.	Resistance.
Plates 1 yard apart on the level plain,	68, on a mountain,	152.
,, 5 ,, ,,	97, ,,	—
,, 10 ,, ,,	102, ,,	222.
,, 20 ,, ,,	109, ,,	—
,, 50 ,, ,,	123, ,,	531.
,, 100 ,, ,,	— ,,	849.

The resistance diminishes with the depth to which the plates are buried.

When buried 4 inches the resistance was	91.
,, 10 ,, ,,	83.
,, 40 ,, ,,	74.
,, 80 ,, ,,	70.

The size of the plates has the greatest influence on the resistance.

If a plate containing 1 square foot of surface gives a resistance of 174,

A plate of 4 square feet will give a resistance of	140.
,, 16 ,, ,, ,,	81.
,, 25 ,, ,, ,,	47
,, 32 ,, ,, ,,	31.

But after a certain *size*, varying with the conducting power of the soil around the plates, the resistance remains constant.

In the sea this limit is very quickly reached.

After a certain *distance*, varying with the conducting power of the soil and the size and depth of the plates, a further increase of distance makes no difference in the resistance.

This diffusion or conduction does not take place solely in the direct line between the two plates, but extends in curved lines on all sides. It is thus easily seen why the resistance decreases with the depth to which the plates are buried is

less on a plain than on a mountain, and is greater when a portion of soil is isolated by being placed in a box, for then the conduction takes place only in the direct line, and there can be no diffusion.

129. On short lines the resistance of the earth to the diffusion of the current is a matter of the greatest importance.

If the earth terminals of the several circuits or wires are connected to one and the same earth-plate, it becomes a question of comparative resistances, whether a current sent on one wire shall diffuse itself through the earth, or shall divide between the earth and the other wires. The earth plates should in this case be large, and be buried deep in soil wet at all seasons.

130. It sometimes happens that an "earth cannot be found" in places where there is but a thin layer of soil covering rock, or where the soil is constantly dry.

Instead of connecting all the wires to the same earth-plate, use separate plates buried twenty yards or more apart, so that the resistance of the soil between the plates is greater than the resistance of the earth to the diffusion of the tensions.

131. To test an earth-plate, send a current on one wire, and place a sensitive galvanometer on the shortest of the others; one fixed on separate poles, if there are more than one line. If no current passes through the galvanometer, the earth is perfect.

132. A water or gas pipe is preferable to a plate, because of its larger surface. Care must be taken to connect to the main street gas pipe, as the joints indoors are frequently packed with white lead. It is best to use both water and gas pipes, so that, if one be under repair, the other shall complete the circuit; a well soldered connection should always be made.

133. A narrow deep trench filled with coke, in which a copper plate, or what is better, a strip of lead, is buried, may

sometimes be used, bearing in mind that the object is to expose as large a surface as possible.

Plates must always be buried *flat*, and not coiled into a cylinder or spiral, and upright rather than horizontal.

134. On connecting up a circuit of less than ten miles, it frequently happens that a permanent current appears on the instrument, arising from the earth-plates forming a battery. If an iron gas pipe be used for an earth at one end, and a lead water pipe or a buried plate of copper at the other, a current is always set up.

It is necessary, then, to be careful that both earths be as nearly as possible alike, and to change one or both till the current ceases.

PART IV.

INSULATION.

135. When a wire is suspended on poles it is fixed to *insulators*, to prevent the escape of the current at the points of support. When it is carried through wet tunnels, underground, or through water, the insulation must be *continuous*, and the wire is covered with gutta percha or India rubber.

136. The insulation of a line is never perfect, even in dry weather. There is a loss at every point of support, even when the insulators are clean, and this is considerably increased when their surfaces are damp, more especially so when dusty, dirty with smoke, or salt from being near the sea. When the wires are not galvanized, a slight coating of rust is formed upon the insulators by the rain dropping from the wires; this is very hurtful. The wires are often hung with spiders' webs, which, when covered with dirt and moisture, conduct; and on a long line the leakage from wire to wire through damp air cannot be altogether without effect. Though it may be extremely small at any given point, so small, indeed, that the tests hitherto made have failed to discover any conduction whatever, yet the total surface exposed is enormous, being as much as 220 square feet per

mile of No. 8 wire. A very rough test will show how much insulation is affected by dirt or smoke, and too much care cannot be taken to keep the insulators clean.

137. As damp affects insulation so seriously, great care was taken in the earlier telegraphs to protect insulators from the rain by wooden roofs; but it has been found that such coverings are not only useless, but injurious. They do not themselves insulate, they afford no protection in fogs or continued rain, for then every part becomes equally damp. They harbour spiders, which spin their webs over and among the wires. They hinder the drying of the supports, and prevent the rain washing off the dust which covers the insulators. The inside of a hollow insulator, or that part which is protected by a wooden arm, is always dirtier than those parts which are fully exposed, and damp dirt conducts far better than a film of dew or clean rain water. Insulation is frequently improved by a heavy summer shower. There is a great disadvantage in placing insulators under bridges, where they are quickly covered with smoke, and are protected from the cleansing effect of rain. The umbrella-shaped insulator secures all the advantages of the roof in keeping an insulating surface dry in moderately wet weather, while it adds to its insulating power by increasing its length (102).

138. Complete exposure is most of all desirable on the sea coast. It is true that a cover may protect an insulator from the effects of spray, but during storms the air is impregnated with water holding salt in solution, and this when evaporated lines the insulator inside and out with a thin layer of salt. If all the surface of the insulator were exposed, the next shower of rain would wash away this coating; but if covered, the salt would be left, and the insulator would gain considerable conducting power with the slightest damp.

139. In order to form a correct conception of the relative merits of various kinds of insulators, it is best to consider them not as *insulators*, but as *conductors*, whose value depends on their resistance to conduction.

140. In insulators similar in other respects, the largest in diameter will conduct best; it is, therefore, the worst insulator, for, as the conduction takes place over its surface, the greater the breadth of this surface the better will it conduct: for instance, the surface of an insulator six inches long and four inches in diameter may be considered as consisting of $4 \times 3 = 12$ *strips* one inch wide, six inches long. If the insulator were half this length and half this diameter, its conducting surface would equal $2 \times 3 = 6$ strips one inch wide, three inches long. The resistance of the small insulator would be exactly equal to that of the larger one, for though there are but half the number of *strips*; each of them is but half the length, and therefore has but half the resistance of those into which the first is supposed to be divided. It gains in decreased width what it loses in decreased length.

141. The best insulator is that which has the smallest diameter possible with the greatest length of surface between the wire and the bolt, or support. Length is most easily given by hollow or cup-shaped insulators placed inside each other.

142. A tube or double cone surrounding the wire, and supported at its centre, must be *double* the length of an insulator fixed at its end (such as an invert) to be equally effective; because the current escapes from the wire at each end of the insulator in the former, and at one end only in the latter case.

143. The affinity of a material for moisture, or its power to attract damp, is an important point. Glass, though a better insulator than porcelain, becomes damp much sooner. If a glass tumbler and a teacup, each filled with cold water,

be brought into a damp warm room, the glass will be covered with dew long before the porcelain shows any signs of moisture. The glass supports of apparatus used for experiments on frictional electricity must be varnished with shellac, to lessen this affinity for moisture.

Ebonite insulates much better than glass, and is far less apt to become damp than even porcelain. It is the best material yet known for insulation, but we have not had sufficient experience of its durability to judge of its power to bear exposure to the weather.

144. Another advantage of a small insulator is, that it is more likely to be perfect. Large masses of clay are apt to crack in drying, or in the kiln; they are frequently not vitrified throughout in burning, and are therefore more or less porous. Small masses dry readily, and are easily burned. Porcelain when not well baked is a conductor; if overbaked it is apt to swell and become porous. Stoneware is not injured by overbaking, and is one of the best non-conductors we possess. It is therefore much used. There is a great advantage in forming an insulator of separate hollow pieces or cups placed inside one another and fastened with cement; if one is defective there is a probability the others will be sound, and if the pin or bolt be covered with an insulator (such as ebonite), insulation will not be destroyed if the earthenware be entirely useless.

145. Every insulator should be tested before it is used. If made of porcelain, or any other ware apt to be porous, part of the glaze should be ground off.

They should be placed in a trough of dilute sulphuric acid, or salt and water, allowed to remain several hours, and tested to prove if the bolt is perfectly insulated from the liquid in the trough, using a sensitive galvanometer.

146. An insulator which depends for its efficiency upon

its glaze is useless. All glazes crack and admit the damp. They are, however, useful when they give a smooth surface, to which dirt will not adhere, and which will be washed clean by rain.

147. When insulation is imperfect, the current escapes to the earth down the poles, and into the other wires in proportion to their several resistances; and as the shorter the wire the less the resistance, the tendency is to escape from a long circuit into a short one.

148. When the current escapes to the *earth* the signals are simply weakened, and the loss can be made up by increased battery power. But when it leaks into *another wire* it confuses the signals passing upon that wire, and when signals are sent on the second wire the current interferes with that passing on the first wire. Thus, the working is seriously affected by what is termed "*weather contact,*" and the confusion increases with each increase of battery power.

149. But when the insulators are placed upon a metallic post, or connected by a wire to the earth, so that all the current which *leaks* over their surface may have a path provided which shall conduct very much better than the line wire, the leakage will divide itself in the inverse proportion of the two resistances, and will pass almost entirely to the earth. The extra current thrown into the circuit by the lessened resistance can be provided for by an increased battery, without affecting the other circuits on the same poles. The effects of contact are thus entirely obviated.

150. When the wires touch the ground, a wet wall, the boughs of trees, grass, or the like, part of the current escapes to the earth.

151. When they touch one another, or are connected by wet waste, kitestrings, or other conductors, the current divides itself between the two wires.

152. These faults are called *"earth"* and *"contact."* Earth, technically speaking, being contact with the ground; contact, a contact with another wire.

153. If a wire lies on the metals of a railway, or other perfect conductor in communication with the earth, the resistance being nothing compared with that of the wire, all the current will pass to the earth, and none to the receiving station.

154. If the metal is rusty or dirty, or the wire simply lies on the ground, the fault will offer some resistance equalling that of a certain length of the line wire.

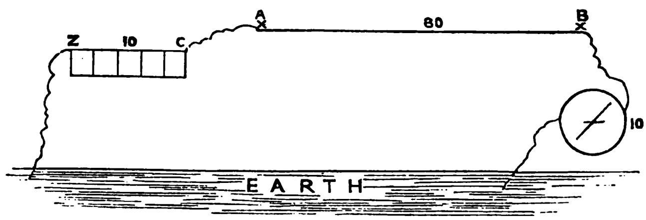
155. Thus a fault may be said to offer no resistance at all, or a resistance equal to so many miles of line.

156. The current divides at the fault, in an inverse proportion to the resistance of the paths open to it. The greater the resistance of the fault, the more current will pass on to the receiving station, and *vice versa.*

157. The effect of a fault, whether earth or contact, is to decrease the resistance of the circuit, to work the batteries harder by augmenting the current passing out to the line, and to decrease the current received at the distant station.

But its effects on the signals will depend on its position on the line, and this position will determine also, which of the two stations shall be most affected by it, for a fault which prevents B reading A may not prevent A reading B.

158. Let A B be a wire on which A is the sending and B



the receiving station. Let it have a resistance of 80 units, and be perfectly insulated.

Place a set of batteries at A, having an electro-motive force of 1,000, and a resistance of 10 units; connect one pole to line, the other to earth. Place an instrument having a resistance of 10 units at B.

When perfect, the total resistance of the circuit will be—

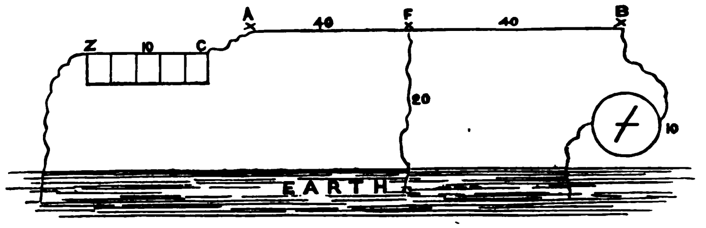
$$\left.\begin{array}{l}\text{80 units line}\\ \text{10 units instrument}\end{array}\right\} = \text{L.}$$
$$\text{10 units battery} \qquad = \text{R.}$$
$$\overline{\text{100 units.} = \text{R} + \text{L.}}$$

As the force of the battery is 1,000, the current will, by Ohm's law, $C = \frac{E}{R+L}$, be $\frac{1000}{100} = 10$. Then 10 parts of the whole force of the battery will act on the instrument (113).

The strength of the signals will be $= 10$.

159. Suppose, now, a fault to occur connecting the wire to the earth, and offering a resistance equal to that of 20 miles of the line. This "leak" will lessen the total resistance of the circuit in the same degree as if a wire 20 miles long, and similar in all respects to the line wire, were fixed to the line at the fault, and connected to the earth.

The current passing out from battery to line will be increased, but the current will split or divide at the fault into two parts, according to the resistances of the two routes open to it—the greater part following the shorter route. Thus the effective current, or that acting to produce signals, will not be that which passes out from the battery to the line.



160. *First case.* Let the fault be in the centre of the line of ... ... 80 units.

The two circuits beyond the fault will then be :—

1. That by the line and instrument, $40+10=$ 50 units.
2. That by the fault itself ... .. · ... 20 units.

Their joint resistance* will be $\frac{50 \times 20}{50+20}=$ ... 14·3

Adding the resistance of the battery, 10 units, and the wire to the fault, 40 units ... ... 50·0

The total resistance will be ... ... 64·3

The current passing out to line $\frac{1000}{64 \cdot 3}=15 \cdot 5$ parts instead of 10.

The two circuits between which the current will divide at the fault are 20 units and 50 units, and are in the proportion of 2 to 5, so that $\frac{2}{7}$ of the whole will pass by the line, and $\frac{5}{7}$ by the fault. Dividing the current passing out to line into seven parts and multiplying by 2, will give the effective current, or what amounts to the same thing, $\frac{15 \cdot 5 \times 2}{7}$ gives 4·4 as the strength of the signals.

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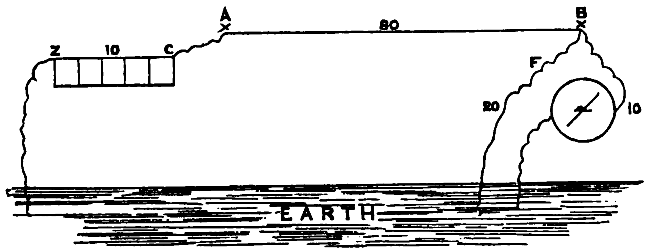
* See Notes.



Second case. The fault at the receiving station B. The two circuits beyond the fault will be :—

1. That by the instrument = 10 units.
2. That by the fault = 20 units.

Their joint resistance $\frac{20 \times 10}{20 + 10} = 6{\cdot}6$ nearly.

The resistance of the entire circuit :—

Battery...	10	units.
Line	80	units.
Instrument and fault	6·6	units.
Total	96·6	units.

The current leaving the battery $\frac{1000}{96.6} = 10{\cdot}35$ nearly.

The divided circuits at the fault are 20 units and 10 units, and are in the proportion of 2 to 1.

Thus the current divides into three parts, two of which will pass through the instrument, and the strength of the signals will be $\frac{10{\cdot}35 \times 2}{3} = 6{\cdot}9$ parts instead of 10.

Third case. The fault at the sending station A. The two circuits beyond the fault will be :—

1. By the instrument and line 90 units.

2. By the fault, 20 units.

Their joint resistance $\frac{90 \times 20}{90+20}=$	16 nearly.
Add battery	10 units.
The total resistance will be only	26 units.

Current leaving battery $\frac{1000}{26}=38$.

The two circuits beyond the fault are in the proportion of 2 to 9, and $\frac{38 \times 2}{11}=6{\cdot}9$, will be the strength of the signals instead of 10.

Fourth case. The fault 20 units from A.

$60+10=70$ units, line and instrument.

20 units fault,

are the two circuits between which the current will divide, and $\frac{70 \times 20}{70+20}=15{\cdot}5$ their joint resistance.

Entire resistance of circuit:

Battery	10	units.
Wire to fault	20	„
Beyond fault	15·5	„
Total	45·5	„

Current leaving battery $\frac{1000}{45{\cdot}5}=21{\cdot}7$ nearly, and

$\frac{21{\cdot}7 \times 2}{9}=4{\cdot}8$ nearly, the strength of signals.

Fifth case. The fault 20 units from B, its resistance 20 units.

$20+10$ units, line and instrument.

$\frac{20 \times 30}{20+30}=12$ joint resistance.

Total resistance:

Battery	10 units.
Wire to fault	60 ,,
Beyond fault	12 ,,
Total	82 units.

$\frac{1000}{82}=12{\cdot}2$ nearly—the current leaving the battery, and

$\frac{12{\cdot}2\times 2}{5}=4{\cdot}8$ nearly, the strength of signals.

Thus on a circuit consisting of:—

Line wire of... ... 80 units resistance;
Instrument ... .. 10 ,,
Battery ... ... 10 ,, and with an
Electro-motive force of 1000 ,,

The strength of signals when the line is perfect will be	10·0 parts.
When a fault of 20 units resistance is in the centre	=4·4 ,,
The same fault 20 units from receiving station	=4·8 ,,
,, ,, ,, 20 units from sending station	=4·8 ,,
,, ,, ,, at the receiving station	=6·9 ,,
,, ,, ,, at the sending station	=6·9 ,,

Thus, the effect of a fault is greatest when in the centre of such a line.

161. The following formula will be found more convenient for these calculations. It gives the effective current, or the strength of the signals:—

1. Call the resistance of the line between the sending station and the fault, including the battery and apparatus, R.
2. Call the resistance of the line beyond the fault, including the receiving apparatus, r.
3. And the resistance of the fault itself, f.
4. Let the electro-motive force of the battery be E.

5. Multiply R by r.
   Multiply R by f.
   Multiply r by f.
   Add the three products together, call their sum No. 5.
6. Multiply f by E, divide the product by No. 5, the quotient will be the strength of the signal at the receiving station.

Expressed algebraically, the formula reads thus:—

$$\frac{Rr+Rf+rf}{Ef}=\text{strength of signals.}$$

The first case will be calculated thus:—

$$R=50. \quad r=50. \quad f=20. \quad E=1000.$$

$$\begin{aligned}50\times 50&=2500\\ 50\times 20&=1000\\ 50\times 20&=1000\\ \hline 4500&=\text{No. 5.}\end{aligned}$$

$20\times 1000=20{,}000$, which divided by 4,500 gives 4·4 as the strength of the received signals.

In the fourth case. R=30, r=70. f=20 and E=1000.

$$\frac{1000\times 20}{30\times 70+30\times 20+70\times 20}=4{\cdot}8.$$

In the fifth case. R=70. r=30. f=20 and E=1000.

$$\frac{1000\times 20}{70\times 30+70\times 20+30\times 20}=4{\cdot}8.$$

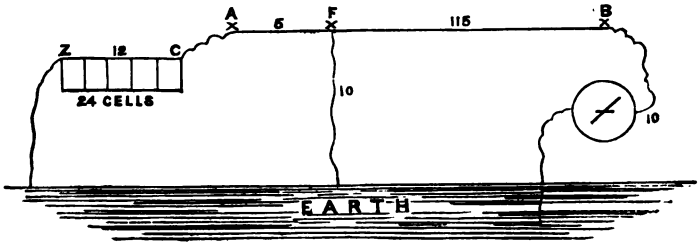
162. It will be seen that the figures in the two last calculations are merely transposed. Thus, when the resistance of the battery is equal to that of the receiving instrument, a fault arising at a given distance from the sending end of the line will have an effect on the signals equal to that of the same fault the same distance from the receiving end.

Both stations will be equally affected by it.

But, practically, the battery of a long circuit as it consists of many cells, offers much more resistance than the instru-

ment, and therefore the centre of the *line* will not be the centre of the *circuit*, which comprises not only the line wire, but the battery and instrument. The effect of a fault on signals will therefore be greater when nearest the *sending* station, thus :—

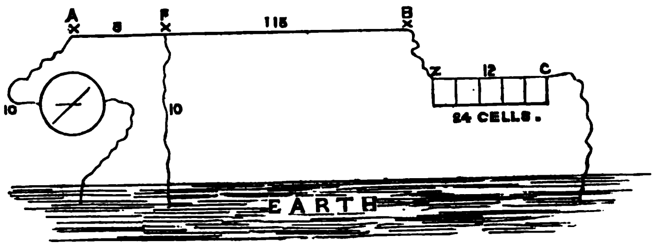
163. Take a case in which an earth of 10 units resistance occurs 5 units from A, and 115 units from B. The resistance of the instrument or galvanometer being 10 units, and of the battery of 24 cells 12 units, the electro-motive force 10,000.



When A sends a signal from 24 cells,

$$E=10,000, \quad R=17, \quad r=125, \quad f=10.$$

$$\frac{10,000 \times 10}{17 \times 125 + 17 \times 10 + 125 \times 10} = 28,$$ will be the effective current received at B.



When B sends,

$$E=10,000, \quad R=127, \quad r=15, \quad f=10.$$

$$\frac{10,000 \times 10}{127 \times 15 + 127 \times 10 + 15 \times 10} = 30,$$ effective current received at A.

Now calculate the effect of increased battery power, say 48 cells.

A sending :—

E will be doubled $=20{,}000$; the battery resistance is also doubled.

$R=$ battery $24+$ line $5=29$.

$r=$ instrument $10+$ line $115=125$.

$f=$ as before 10.

$$\frac{20{,}000\times 10}{29\times 125+29\times 10+125\times 10}=38 \text{ effective current.}$$

B sending :—

$E=20{,}000$.

$R=$ battery $24+$ line $115=139$.

$r=$ instrument $10+$ line $5=15$.

$f=$ fault $=10$.

$$\frac{20{,}000\times 10}{139\times 15+139\times 10+15\times 10}=55 \text{ effective current.}$$

Here, as the resistance of the battery increases, the difference in the effect of the fault on signals received at the two stations increases also.

Double the size of the plates, halving the resistance.

A sending :—

$E=20{,}000$.

$R=$ line 5, battery $12=17$.

$r=$ line 115, instrument $10=125$.

$f=10$.

The effective force is 56.

B sending :—

$E=20{,}000$.

$R=$ line $115+$ battery $12=127$.

$r=$ line $5+$ instrument $10=15$.

$f=10$.

The effective current is 60.

Here the effective current is just double that of 24 cells of the smaller size. The battery resistance having been halved, the total resistance is the same as with 24 cells, while the electro-motive force is doubled.

164. To sum up the foregoing calculations and extend them in a tabular form :—

If on a wire 120 units long there be a fault offering a resistance of 10 units, situated 5 units from the end A, and if the recording apparatus have a resistance of 10 units the battery, $\frac{1}{2}$ unit per cell, and the electro-motive force (E) 10,000 per trough of 12 cells, then the effect of the fault on the current received at each terminal station is as follows :—

No. of Cells.	Resistance of Battery.	E.	Strength of Signals received at A near the fault.	Strength of Signals received at B distant from the fault.
24 small	12 u.	10,000	30	28
48 „	24 „	20,000	55	38
96 „	48 „	40,000	94	47
192 „	96 „	80,000	147	53
24 double	6 „	10,000	31	36
48 „	12 „	20,000	60	56
48 treble	8 „	20,000	61	66*
96 double	24 „	40,000	110	77

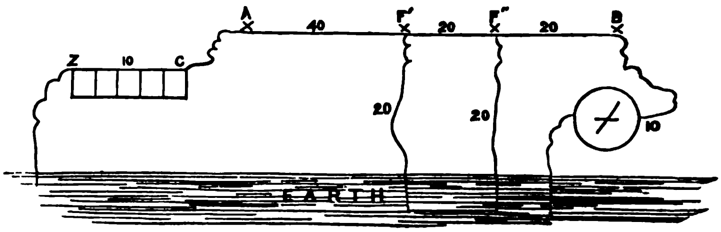
The current received from 24 cells when the line is perfect is 70, and from 48 cells 130.

165. In France where the resistance of the coil is about 100 instead of 10 units, the station nearest a fault is most

* This case is an exception to the general rule that the signals received at the station farthest from the fault are more enfeebled than those received at the station nearest it. The reason is, that in this case only, is the resistance of the battery less than that of the coil of the apparatus.

affected by it, hence their works on practical telegraphy appear to lead to a contrary conclusion to that given above. (See Blavier.)

166. When there are several faults the calculation is much more difficult; with two faults the law is this:



Taking the same circuit as in the former cases (158), with two faults, each of 20 units resistance F′ and F″, the first 40 units from A, the second 20 units from B.

When the line is perfect, the resistance will be 100 u. and the current $\frac{1000}{100} = 10$, as before.

Units.

With one fault at F′ the resistance $\frac{50 \times 20}{50+20} = 14{\cdot}2 + 50 = 64{\cdot}2$.

With one fault at F″ „ $\frac{30 \times 20}{30+20} = 12 + 70 = 82{\cdot}0$.

With both faults,

Resistances beyond F″ = 12 units.

„ between F′ and F″ = 20 units.

Total resistance beyond F′ 32 units.

The joint resistance of F′ and the circuits beyond it are

$$\frac{32 \times 20}{32+20} = \frac{640}{52} = 12{\cdot}3.$$

Add the battery and the line from A to F′ 50·0.

Total new resistance 62·3.

Current leaving the battery $\frac{1000}{62 \cdot 3.}=16$ parts instead of 10. This current will divide at F′, between the wire and the fault, in the inverse proportion of the resistances 20 and 32, and 6·1 parts will go towards B; this will split again at F″, between the two resistances 20 and 30, and 2·4 parts will gain the receiving apparatus.

167. Occasionally, when insulation is very defective, a wire will test alike whether disconnected at the distant end or not, yet sufficient current will reach the instrument to give readable signals.

Take a circuit of 40 units, and let there be a fault of 2 units' resistance in its centre,

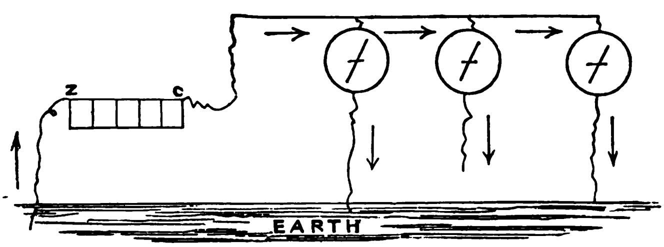
$\frac{20 \times 2}{20+2}=\frac{40}{22}=1 \cdot 8$ will be the resistance beyond the fault.

$\frac{\text{Force of battery}}{\text{Resistance of circuit}}\ \frac{1000.}{1 \cdot 8+20}=45 \cdot 8$ the current passing out to line.

$\frac{45 \cdot 8 \times 2}{22}=4 \cdot 1$, current reaching the instrument.

If the wire be disconnected at B, the total resistance of the circuit will be 22 miles instead of 21·8, and the current passing out to line 45·4, instead of 45·8, or almost exactly the same as when not disconnected.

168. The laws of *derived circuits,* or faults, as already explained, will enable us to calculate the effect of connecting instruments, so as to divide a current between them, thus :—

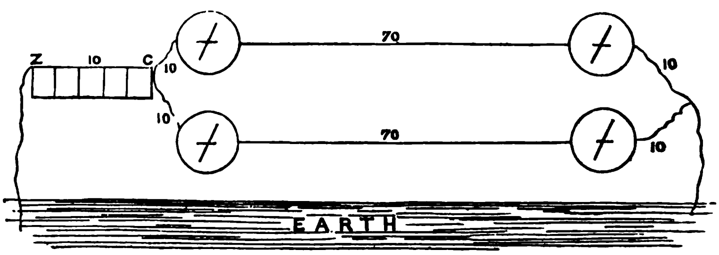


169. The same law will enable us to explain how it is that there is no appreciable difference in the signals whether the needles of a double-needle instrument are worked singly or together, although the effect of working both at once is precisely the same as establishing an earth of equal resistance to the entire circuit excepting the battery, close to the sending station.

Take the line of 70 units, with battery and instruments of 10 units each resistance, and force of battery 1,000 :

When one needle only is used, $\frac{1000}{100}=10$ will be the signal.

When both are used the current will divide thus at A :



And we have $\frac{90 \times 90}{90+90}=45$ as the joint resistance of the two wires.

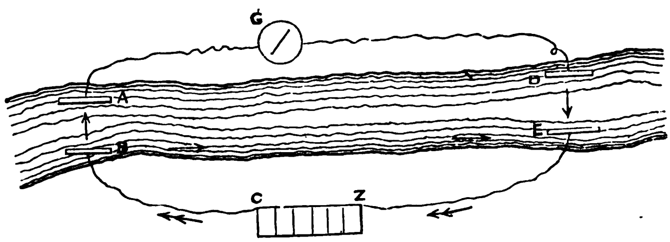
Adding the battery 10 miles, $\frac{1000}{55}=18$ will be the current passing out to line, and 9 the signal, instead of 10. If the battery had less resistance, the difference of signal would be less ; and if it were nothing, the signal would not be affected at all. But the battery being harder worked would get weak much more quickly.

170. Thus, two or more wires of similar resistance, if of considerable length, can be worked from the same battery, provided the lines be well insulated and the current sent on

each be in the same direction; for if the copper be put to earth on one circuit, while the zinc is to earth on another, the battery would be on "short circuit." Double sets of batteries, one for the positive and the other for the negative current, allow of reversals; but the trials hitherto made with what have been termed "universal batteries" have not been perfectly successful in producing steady currents.

A great objection to this method is, that a battery fault affects all circuits connected with it, and a line fault renders the current very variable, as may readily be seen on a double-needle circuit.

171. The law that a current *splits* or divides according to the resistances of the several paths open to it enables us to explain the method of signalling across rivers without wires.



Part of the current will take a straight course through the water between the plates B and E, and part make the circuit of the wire and galvanometer; that is across the water from E to D, along the wire to A, across again from A to B, and along the wire to the battery. The amount following either path will depend on their comparative resistances, and in order that the direct route C B E Z shall offer more resistance than that through the galvanometer, it is necessary that the distance from plate to plate along the bank shall be considerably greater than the breadth of the river.

172. The practical question then arises, how to provide

for loss of current from defective insulation in the cheapest manner, without making the signals unnecessarily strong when the line is in good order.

The calculations already given (164) prove that *increasing the size of the plates* most effectually provides for the extra current required, and actual experiment confirms the theory.

And when a large number of small cells are placed on a faulty line the resistance of the circuit is so small, and the electro-motive force so great, that the current soon falls from the exhaustion of the battery, and becomes less than that from half the number of a larger size. This agrees with experience.

173. Another objection to the use of a large number of cells on a faulty circuit is this.

When a battery is disconnected, its poles have equal and contrary tensions, and when one pole is connected to the earth the tension of that pole falls to zero, or becomes lost (26). If the other pole be connected with an insulated conducting wire, it communicates its tension to it, and neglecting for the time losses from bad insulation, the tension of the wire, if equal in resistance and insulation throughout, will be in every part equal to that of the pole of the battery with which it is connected. In this case the wire does not form part of a circuit, being insulated at the distant end.

If the distant end of the wire be connected to the earth it will lose its tension in the same manner in which the battery did, and if the wire be very large, so as to have no appreciable resistance, the tension of the end connected to the battery will become also equal to zero. But if the wire has an appreciable resistance, its tension will vary in a regular manner from the battery end to the distant end which is connected to the earth, and the difference of the tensions of the two extremities, *which is the force urging forward the current,*

will depend upon the resistance of the wire. The diminished resistance of the line decreases the tension of the battery, reducing its *working power* below that of a smaller number of larger cells.

174. At a time when the insulation was far less perfect than at present, and when sand batteries were used, which are much more quickly exhausted than the batteries now employed, Mr. Varley obtained the following results: —

He says: "On a very wet day Bristol could not read from "Lothbury with the ordinary power of 72 cells, showing on "my quantity-galvanometer 40°. I increased the power to "144 cells, yet Bristol was unable to read. I doubled this, "viz., to 288 cells, with only a slight improvement. The "batteries having been at work one hour, and Bristol then "being unable to read, I tested them again. They had "receded in quantity from 40° to 25°, the galvanometer "being put in short circuit with the battery when testing its "power; when the galvanometer was put into the line "circuit the electricity that left the battery indicated 14°. "I now connected up the 288 cells in two series of 144 cells "each. The copper poles of each set were connected to the "copper terminal of the instrument, and the two zinc poles "to the zinc terminal of the instrument. The battery thus "arranged was equivalent to 144 cells of double the usual "surface. When this was joined to the line the electricity "leaving the battery indicated 20°. Bristol now read us "well, and reported signals good. When the battery was "again joined up in one series of 288 cells, Bristol com- "plained, and could not read.

"From the foregoing experiments it is evident that the "intensity of the stream leaving Lothbury was greater from "144 large cells than from 288 small."

The diminution of power (which is very common in wet

weather) was of course due to the increased work thrown upon the battery plates. When they were connected side by side "for quantity," each plate was worked less than half as hard as before.

Mr. Varley goes on to say: "I invariably find on the "evening of a bad day that the batteries have decreased in a "very decided, though irregular, manner. On a late occa-"sion the batteries on the Bristol circuit, which showed 38° "in the morning, had at noon reduced to 22°. I then pur-"posely added 144 cells to them *intensitively*, for Bristol was "complaining. This addition enabled them to read. About "2 p.m. Bristol complained again. I tested the batteries, "and found that the original 72 cells gave only 3°. Upon "cutting the latter out of the circuit, and leaving on the "144 cells that had been used as auxiliary, Bristol read us "again. This latter shows that the original battery of 72 "cells was so reduced that it offered more obstruction than "assistance."

175. Faraday has shown that in a voltaic battery the chemical action in each cell is exactly proportional to the quantity of electricity flowing through it. Now, every part of a circuit (including, of course, the battery), whatever be its form, nature, or resistance, is traversed in a given time by equal quantities of electricity; just as in a river the same quantity of water passes any given part of the channel each minute, whether the stream be narrow or broad, shallow or deep, because each part is supplied by that which precedes it, and in the like manner supplies the succeeding length. From this cause the chemical action in each cell is equal where there is no waste from local action (36), an equal quantity of sulphate of copper is decomposed, and an equal weight of zinc dissolved, in each cell in the series. That is to say, if in one cell of a series of 100, one ounce of sulphate of copper be

decomposed, exactly one ounce (neither more nor less) will be decomposed in each of the other 99 (it matters not whether these cells are active, as in a battery, or not); therefore, to circulate a given quantity of electricity, an equal amount of sulphate of copper is consumed in every cell used to circulate it.

For every 32 lbs. of metallic zinc dissolved, 124 lbs. of sulphate of copper will be decomposed, and about 32 lbs. of metallic copper deposited upon the copper plates.

176. "If, therefore," Mr. Varley says, "144 large cells will "produce a current whose working power is the same as "that from 288 small cells, and which consequently produce "signals of exactly the same strength, the consumption in "*each cell* will be exactly the same in *either case*; but as in the "former a series of only 144 cells is used, the total consump-"tion will be exactly one-half of that in the series of 288 "cells. The amount of electricity passing through each cell "determines the quantity of material consumed."

177. The following results were obtained by Mr. C. V. Walker in actual experiment on a very bad line of $5\frac{1}{2}$ miles, including a defective tunnel. The current received at the distant end was :—

From	24	cells,	ordinary size	... ...	10
,,	24	,,	double ,,	... ...	24
,,	24	,,	treble ,,	... ...	27
,,	24	,,	4 fold ,,	... ...	30
,,	24	,,	5 fold ,,	... ...	31
,,	24	,,	6 fold ,,	... ...	32
,,	48	,,	ordinary ,,	... ...	19
,,	48	,,	double ,,	... ...	37
,,	48	,,	treble ,,	... ...	46
,,	72	,,	ordinary ,,	... ...	21

From 72 cells, double size	...	...	43
„ 96 „ ordinary „	...	...	23
„ 120 „ ordinary „	...	...	26

178. There is a disadvantage in making up a quantity battery by connecting batteries of small plates "side by side" (123). Unless they are perfectly equal in power and conductibility, the stronger will have a tendency to send a current back through the weaker; for a battery must not be considered merely as a producer, but also as a conductor of a current.

When Daniell's batteries are thus associated for "quantity" for a considerable time, one must, sooner or later, overpower the other, when the sulphate of copper of the weaker battery is driven through the porous cells, and copper is deposited on the zinc, annihilating the electro-motive force, and producing great local action. Hence it is much better to use large plates, equal in size to two or more of the small ones: that is, to have one of 32 square inches, rather than two plates of 16 square inches each placed side by side.

179. When a battery with larger plates than the rest is arranged in series with others on a circuit, the electro-motive force is the same as if all the plates were of the same size, but the quantity of electricity is increased, because the resistance of the circuit is reduced by as much as the large cells conduct better than the small ones (109). But the chemical action will be more powerful on the small zincs than if all the plates had been the same size; and as the same quantity of zinc will be dissolved in the small cell as in the large, the small cells will be *worked harder* than the large ones, and will more rapidly become weak (46).

PART V.

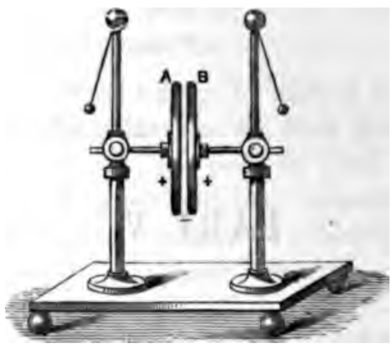
INDUCTION.

180. In addition to the power of communicating a *charge* by spark or contact, an electrified body exerts a peculiar influence on all conducting bodies near it, which increases if they are made to approach, and diminishes if they are removed to a greater distance, nearly ceasing after a certain limit of distance has been attained.

This influence on conductors not in contact is called *Induction.*

181. When an electrified body is brought sufficiently near an insulated unelectrified conductor, the natural electricity of the latter is decomposed, the electricity of the *same* name (positive or negative) being repelled, and that of the opposite name being attracted; so that, however thin the body may be, even if it be a piece of gold leaf, its opposite sides will have contrary tensions. The induction, strictly speaking, does not take place on the conductor, but on the adjacent surface of the air, or the dielectric which coats or covers the conductor.

182. Take two insulated plates of metal, A and B, connect each to a separate electroscope (17); charge A, its electroscope will diverge; bring it near B, taking care that a spark be not



allowed to pass between them, so as to charge B in the ordinary way, the electroscope connected with A will remain divergent, because the plate remains charged, and that of B will diverge, because of the induction exercised upon B by A.

Separate the plates, A will remain divergent, but B will cease to show signs of electricity, because the inductive influence of A has ceased.

183. Thus: if the plate A is electrified positively, and made to approach the insulated unelectrified plate B, its positive electricity decomposes the natural electricity of B, attracting its negative to the side next A, and repelling the positive to the other side of the plate. When A is removed, the two separated electricities of B recombine, and it regains the neutral unelectrified state, while A has neither gained nor lost anything by its action on B.

184. If when the two plates are near each other we touch A, we shall discharge it, and all electrical signs will cease in both plates.

If we touch B instead of A we shall not discharge A, but we shall remove from B the positive portion of its natural electricity, which has been separated by the influence of A. It

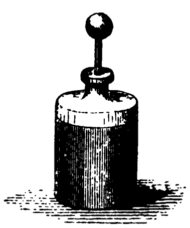
will escape to the earth through the finger, leaving B charged negatively.

This negative charge will be held fast by the positive charge of A, and will exert no influence on surrounding bodies, so that the electroscope of B will cease to diverge, as if that plate had lost all electrical tension.

If we now touch A we shall not discharge it, as we should have done in the first instance, because of the inductive influence of B. In fact, the reaction of the opposite charges in the two plates prevents either being entirely discharged by a single touch, unless both are touched at the same moment.

185. If the plates are removed beyond the distance at which they can sensibly act upon each other, the electroscopes both of B and A will diverge, for the two charges are now free to act on bodies within their influence, and therefore repel their respective pith balls or gold leaves. Either plate can now be readily and perfectly discharged. If they are made to touch, their respective charges will rush together and neutralize each other.

186. If when the plates are very near one another a piece of glass be placed between them, the inductive effect will be greater than when air alone intervenes. A plate of shellac will increase it further, and sulphur will have a still greater effect. Each insulating substance, or *dielectric* as it is called, has a natural power appertaining to itself with respect to induction, which is called its "specific inductive capacity."



187. A pane of glass coated on both sides with metal foil within an inch of its edge, or a wide-mouthed bottle coated inside and out to within a short distance of its neck, forms a *condenser*. The coated bottle is called a Leyden jar. The foil on the one side may take the place of A, that on the other side the place of B.

188. The condenser is so called because, by its means, we are enabled to condense or accumulate upon a given surface a greater quantity of electricity than it would contain were induction not brought into play. We can also make use of the *specific inductive capacity* of glass, resin, gutta-percha, or other *dielectrics*, still to increase the charge.

189. For as the positively charged plate A, now represented by the inner coating of the jar, is very near B, represented by the outer coating, the positive electricity of the latter will be repelled, and if B is not insulated from the earth, its positive electricity will escape and the outer and inner coatings will be charged, but with opposite electricities. B reacts on A, so that their respective charges are, as it were, held fast the one by the other. A is then able to receive an additional positive charge from an excited body, which it would not have been able to receive but for the influence of B.

190. Faraday considers that a current is conducted along a wire by each successive particle undergoing induction, and discharging itself to the next beyond it. The particles of a *conductor* offer very little obstacle to this induction and discharge, so that the current or transfer of force is carried on with extreme rapidity.

191. When the wire is sufficiently near another conductor to be able to exercise an inductive influence upon it, the exterior induction must be completed by each portion of the wire before the current can pass on to the next. This process occupies a sensible time.

When the wire is fully charged, it conducts precisely as if there were no induction, so long as the current is steady and regular. If it varies, the induction must be increased or diminished, as the case may be, before the variation can be transferred to the distant end; and when the battery contact is broken, the induction must cease in each successive section of the wire before it is fully discharged.

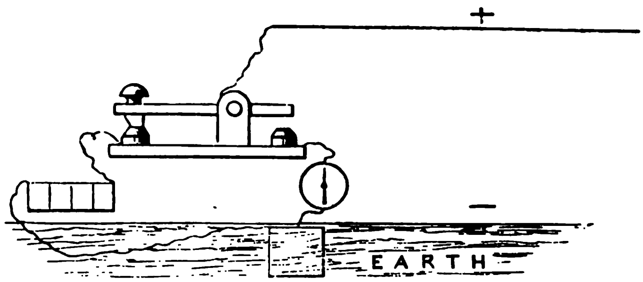
192. Though induction takes place in curved lines as well as in a direct line, yet it diminishes so rapidly with distance, that the effect is always greatest on surfaces *directly* opposed to one another: thus, though a wire suspended on poles influences the wires near it and the earth, the effect is very slight compared with that of a buried wire. Yet it can be made evident by proper means.

193. If one pole of a battery be connected to earth, and the other to a line wire suspended on poles, well insulated and *disconnected* at the distant end, a current will pass into the wire till it is charged, that is, till it has attained the same *static* (126) tension as the battery.

If the battery contact be now broken, and the wire left disconnected, the charge will speedily be dissipated through the air, and by leakage at the supports. But immediately battery contact is broken, if the wire be put to earth at the sending end through an electro-magnet or galvanometer, a *discharge* will take place through the apparatus, as when the plates A and B (185) are made to touch one another.

If the wire is short, the discharge will be completed before the apparatus has had *time* to move. The time increases with the length of the wire (other things being equal) until it attains sufficient duration to affect the apparatus. (See 126.)

For instance: if the key of a Morse instrument, connected to a long well-insulated wire, be pressed so as to charge the wire and be then allowed to fall back very suddenly, the discharge or *return current* will move the relay and produce a signal. When the wire is very long, it is not necessary even that it be disconnected at the distant end, because the resistance is equivalent to partial insulation (100).



194. As induction requires time, it tends to limit the rapidity with which signals can be transmitted. For if the effect of one current has not entirely ceased before that of another commences, the signals will "*run together*" and be confused.

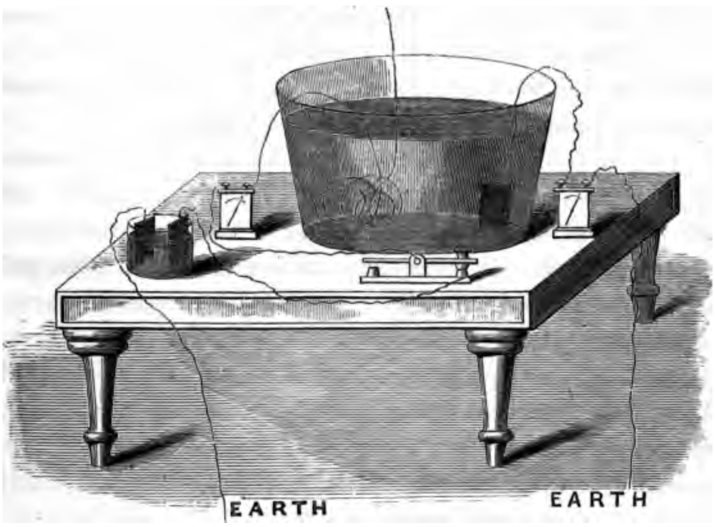
On half a mile of suspended wire 500 or 600 signals may be readily sent per minute; but at a distance of 500 miles the current would appear continuous. By reversing the currents the wire can be discharged more rapidly, and the speed increased.

195. If the line wire were brought very near the ground, the inductive action of the wire and earth would be increased, and the time of discharge increased also; and if it were covered with an insulator and buried, so that the distance were still further decreased, and the wire directly opposed on all sides to another conductor, induction and retardation of signals would be enormously increased, and the discharge or *return current* would be very powerful, because an immense Leyden jar would have been formed, having the wire for its inner and the earth for its outer coating, which being in direct communication with the earth, like the plate B (184) when touched with the finger, would part with the electricity set free by induction, enabling the wire to take up an additional charge from the battery. Each mile of ordinary coated copper wire (No. 16) has an inner surface of about

86 square feet, and an outer surface of 330 square feet. A hundred miles of such wire will expose a very large surface.

Mr. L. Clark gives the following illustration in the "Submarine Report," p. 316.

196. Insulate a large tub filled with water, and place about half a mile of percha-covered wire in it.



Put one pole of a battery of 250 cells to earth, connect the other pole through a key and galvanometer to one end of the wire, leaving the other end disconnected and well out of the water.

Place a copper plate in the tub, connect it by a wire to a second galvanometer, and put the other terminal of this galvanometer to earth. The water of the tub will thus be put to earth through the second galvanometer. If a charge be sent into the half mile of wire by moving the key, electricity of the same kind will leave the water for the earth. Both the galvanometers will move in the same direction, precisely as if they were both in circuit, whereas the circuit is not

completed. There will be this difference: in the case before us the needles will be affected for an instant only, however long we may press the key, while if the circuit were complete they would continue deflected until battery contact was broken.

The water, which is the outer coating of the wire, and which takes the place of the plate B, is put to earth. Hence the portion of its electricity, repelled by the charge given to the wire (or plate A), passes to earth, and an additional quantity passes into the wire from the battery.

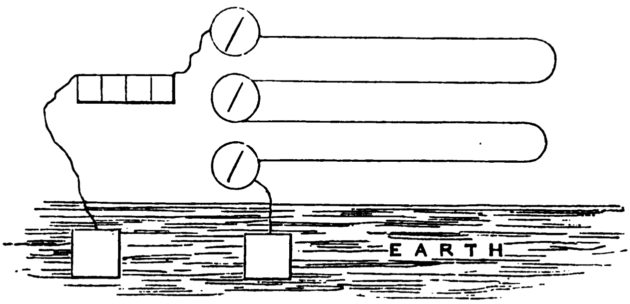
197. If 100 miles of covered wire be placed on a wooden floor, signals may be sent through it nearly as clearly and distinctly as on an ordinary circuit of the same resistance. But if it be put in water, one end insulated, the other end connected through an ordinary needle instrument to earth, and a battery of 40 or 50 cells joined to the instrument, then, if the key be moved as if to send a signal, the needle will be violently deflected for an instant by the current entering the wire to charge it. As soon as the wire is charged the needle will regain the perpendicular, although the key is still held in the position for sending a current.

If the handle be placed upright so as to cut off the battery and put the wire to earth, the needle will again be violently deflected, but in the opposite direction, by the charge escaping from the wire.

198. Now, if the wire had been lying on the floor instead of in the water, the needle would scarcely have moved, however powerful the battery; for though a current would enter into and charge the wire in this case also, the effect would be slight, and last too short a time to do more than barely move the needle (193).

Similar effects will arise if the wire is connected to earth at the distant end, but they will be less marked.

199. If two lengths of 100 miles, or more, be placed on a dry floor, and if a needle instrument be inserted between each length, and one at each end, so as to form a circuit, when



signals are sent in the usual manner, all the needles will move sensibly at the same time, sharply and distinctly.

200. But if the wire be put in water or buried in the ground, and the circuit be completed through the earth in the usual way, the needle at the battery end will move immediately the handle of the instrument is turned; the second needle will not move at the same instant, but a perceptible time afterwards; the third needle later still; and so on, showing the current now travels more slowly than before.

When the handle is caused to break battery contact and put on the earth, a discharge will take place, and the needles will fall back one after the other, commencing with that at the battery end.

201. The practical effect on a needle circuit is this: the sending needle is jerked violently in the reverse direction after each signal, and frequently becomes demagnetized or cross-magnetized by the discharge or return current.

The receiving needle moves sluggishly, and the signals run together, so that a letter of three movements appears like one of a single movement sent slowly.

Signals through buried wires are thus seriously retarded.

202. On a printing circuit the marks run together, each dot being lengthened by the discharge of the electricity "pent up," as it were, by induction.

203. Reversing the current facilitates the discharge at the sending end, by neutralizing the charge with electricity of the opposite name, so that there is not so much to escape at the receiving end. This renders the received signals much more distinct.

204. When a covered wire is coiled into a regularly formed bundle, especially if it be wound upon an iron drum, the discharge at the sending end is in the same direction as the current entering the wire, instead of the opposite direction. By some it is supposed that this is caused by the *induction of a current on itself*, causing a prolongation of the flow of the current in the wire after battery contact is broken. On a short length this is stronger than the "return current," and overpowers it; therefore the return current in a coiled cable *appears* to be in a different direction to that in the same cable when laid out straight.

Mr. C. F. Varley considers this to be purely a magneto-electric phenomenon.

205. In testing a buried wire, or even a well insulated suspended wire, the distance of a disconnection may be estimated by the amount of the return current; for the longer the wire the longer will be the time occupied in the discharge, and the greater its amount.

206. If two or three successive currents be sent into a long buried wire, they will travel on independently of each other. It is even possible to produce alternate waves of positive and negative electricity; that is, to charge the two ends of a wire oppositely.

207. A cable, coated with iron wire, is subject to a large

amount of induction, even when out of the water, because the iron covering is a good conductor.

When coiled, the induction of the current on itself is increased by the reaction of the magnetism set up in the iron coating.

208. A spark may be obtained by making and breaking contact between a battery and an electro-magnet, or even a spiral of wire, when the wire forming them would give no spark if stretched out straight. This increase of effect is due to the same cause as the difference in the direction of the discharge in a coiled cable from that in one laid straight (204).

209. As a wire, even when most free from inductive retardation, takes a certain time to charge, the current will not attain its maximum strength till battery contact has lasted sufficiently long. The more faulty the insulation, and the longer the circuit, the more firmly and slowly must the battery contacts be made.

ATMOSPHERIC ELECTRICITY.

210. There is always free electricity in the air and in the clouds, acting by induction upon the earth and the wires, and creating an opposite tension in them. If the electrical state of the atmosphere were constant, that of the wires would remain constant also, as far as regarded their mutual influence. But it is not so.

When an electrified cloud approaches the wires, it causes currents in them which escape in sparks at the apparatus, demagnetizing or reversing the magnets, or fusing the coils, even although there may be no actual lightning. No case has, however, occurred in which the person in charge of the

apparatus has been injured, for the instrument affords the current a much more ready path than that given by the human body.

Tying a knot in the fine wire of a coil will often cause the spark to jump to the metal frame, and thus preserve the coil from destruction.

During a storm the instruments should be placed on short circuit, by connecting their terminals across; and if the lightning be very vivid, it may be best to disconnect them, putting the line direct to earth.

211. In situations much exposed to lightning, some form of paratonnere or protector should be used, especially at the ends of long pieces of underground work or cables. But they must always be placed indoors, or it will be impossible to preserve their insulation.

212. As long magnets retain their power much better than short ones, it is desirable not to use very short needles in signal instruments, where reversal might be dangerous.

"DEFLECTIONS," OR "EARTH CURRENTS."

Occasionally, especially during the aurora borealis, strong currents, sometimes steady, at other times changing their direction very rapidly, appear in the wires. These currents are not caused by atmospheric electricity, for they cease if a wire be disconnected at one of its ends, and they appear equally in buried as in suspended wires. They seem rather to be caused by currents flowing from one part of the earth to another, which enter the wires by one of their earth connections and leave them by the other, when the currents happen to be passing in that direction.

The wires are constantly traversed by these currents, but it is only at times that they attain sufficient force to affect the apparatus.

They appear most frequently, and have greatest power on lines lying N.E. and S.W.; but it appears that the direction of the current changes with the hour of the day, so that one line may be more strongly "deflected" in the morning, another in the afternoon.

The current has frequently been seen to leave one circuit and to appear upon another previously free.

Communication may be kept open by the use of a magnet, to counteract the effect of the current. But when deflections are very strong and very variable in direction, the best method is to disconnect two wires from earth at both ends, and to use one as a *return wire* to the other in place of the earth.

PART VI.

TESTING FOR INSULATION OR RESISTANCE.

213. It is important that all the principal circuits should be tested daily for insulation and resistance, and that the tests be so recorded as to be capable of being reduced into units of resistance (106). These tests will point out leakages and faulty connections, so as to enable their removal to be effected in very many cases before they interfere with the working of the circuit, besides giving the data necessary for testing for the distance of faults.

The distant stations first disconnect the wires for a certain number of minutes, then put them to earth for a second period by *screwing* a clean wire firmly in each line wire terminal.

214. The French method as stated by Blavier in his manual is as follows, A and B being the two stations:

A sends a current through his "detector" during two minutes.

For the first minute B leaves the wire disconnected, and during the second minute puts it to earth through his own detector.

Each station registers the results.

During the next two minutes B sends the current, and A

makes the changes previously made by B, each registering as before.

The tests made when the wires are *disconnected* show the leakage or loss of insulation, those made when the wires are *to earth* give the resistance of the circuit.

The tests taken at the opposite ends never agree, the resistance of the wire makes a distant fault appear smaller than one near at hand, not to mention other obvious causes of disagreement.

215. Even when the very roughest tests are all that is required, it is clearly absurd to use an amount of battery power sufficient to deflect the needle to the full extent of the scale, for the wires tested may all of them give what is called "full deflection," and yet vary very much in resistance.

216. For these daily tests, each principal office should be provided with a standard resistance coil, say of 50 or 100 units, and an accurate galvanometer, or a differential galvanometer and resistance coils (221), so that the results may be capable of reduction into *units of resistance* (106), for it is obvious that by no other method than the reduction of each test to a common standard of resistance can the observations taken at different times and in different places be compared.

217. An ordinary vertical "detector," though extremely useful for other purposes, gives only rough results when used for this kind of test. Its scale is not correct above 20° (84), and the friction of its pivots interferes with the readings below 40°.

Where no better apparatus is available, it may be used in the following manner, because where the resistance of the battery is small compared with that of the line to be tested it may be neglected, in which case the deflection of a galvanometer increases in proportion to the number of cells used, so that if ten cells give 20°, thirty cells would give 60°.

Increase or diminish the number of cells in each test, so that the deflection of the needle does not exceed 60° and is not below 40°, this being the most reliable part of the scale.

Multiply the results obtained with the smaller number of cells, so as to reduce them to what they would have been with the maximum battery power, provided the scale of the detector were capable of being extended so as to register them.

> Suppose 1 cell gives 60° on the standard of 100 units,
> That 10 cells give 50° on wire A,
> And 40 cells give 40° on wire B,

The tests will be recorded thus—

Standard (of 100 units)		60° × 40 cells		=	2,400.
Wire A,	...	... 50° × 4	,,	=	200.
Wire B,	...	... 40° × 1	,,	=	40.

In the first test the number of cells was one-fortieth of the maximum number. In the second test one-fourth, while in the third the maximum power was employed.

It is very difficult to find a series of cells which are equal in power, so that this system of test is necessarily imperfect. The sensitiveness of the detector might be reduced by the use of Wheatstone's "shunts," were the available portion of the scale less limited.

218. The results obtained by this system can be reduced into units of resistance by inverse proportion, the greater the deflection the less being the resistance.

Thus for wire B—

$$40 : 2{,}400 :: 100 : 6{,}000$$

$$\text{or } \frac{2{,}400 \times 100}{40} = 6{,}000, \text{ the resistance of B.}$$

219. Accuracy sufficient for ordinary purposes may be attained by the use of a tangent galvanometer, with a deli-

cately balanced needle. As the scale is correct throughout, and the friction of the pivot the same at all angles of deflection, a very much greater extent of scale is available, and the "shunt" system can be applied with advantage. The shunt is a wire connecting the two ends of the galvanometer coil, so as to divert a portion of the current and reduce the sensibility of the instrument.

If the shunt be used, the deflection must be multiplied to render the test comparable with others taken without the shunt; thus, if the battery and standard coil give 60° *with* a shunt which reduces the sensitiveness of the instrument to one-tenth, and the wire to be tested give 60° *without* the shunt, the results would be recorded thus :—

100 units $60 \times 10 = 600$: or simply 100 units $= 600$
Wire A $60 \times 1 = 60$ A $= 60$

And the resistance of A reduced to units :—

60 : 600 : : 100 : 1000 units, the resistance of A.

220. The daily tests taken by this method may conveniently be recorded in the following form, so as to be reducible to units :—

Date.	Standard 100 units.	Wires.				State of the Weather.
		A		B		
		Insulation.	Resistance.	Insulation.	Resistance.	
Feb. 19	600	60	1200	10	500	Rain.

221. The most accurate method of testing is that in which the differential galvanometer and resistance coils are employed.

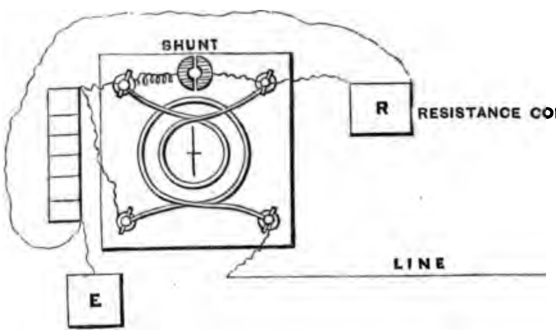
The differential galvanometer is wound with two separate coils exactly equal in their effect on the needle. Therefore, when two exactly equal currents are made to pass

in opposite directions through the coils, they will exactly balance one another, and the needle will not move.

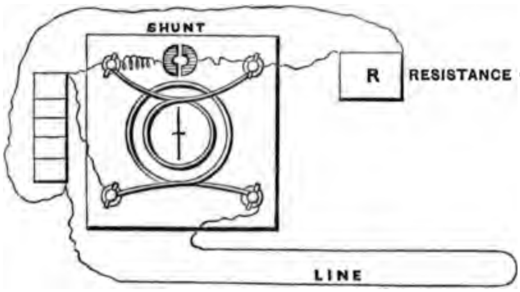
But if the current from a battery be split or divided between two wires of unequal resistances, each connected to one of the coils, the greater part will pass through the shorter wire, and will move the needle; and if the shorter wire be lengthened till it is equal to the longer one, the needle will again be immovable.

In order to be able to balance very great resistances, one coil of the galvanometer is provided with shunts, say of 10, 100, and 1,000, which reduce the effect of the current upon it, so that the 100 units of a set of resistance coils connected with that coil may be made to balance 1,000 or even 10,000 units' resistance connected with the other; for instance, if the $\frac{1}{10}$ shunt is used, the resistance employed to balance the line must be multiplied by 10, and its effect is to extend, as it were, the length of the resistance coils 10 times.

222. In testing for insulation the connections are made thus:—



In testing for resistance or continuity, the line can be connected to earth at the distant end, or what is better, looped with another wire whose resistance is known, or which is exactly similar, thus:—

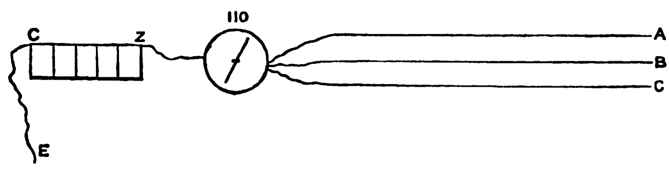


223. When the insulation is good, and equal throughout the circuit tested, the leakage will increase in direct proportion to the length of the wire; and for comparison with other lines the resistance per mile should be obtained by multiplying the resistance of the entire circuit by its mileage, or the longest wire will appear the worst.

This law has been proved experimentally by the writer in the following manner:—

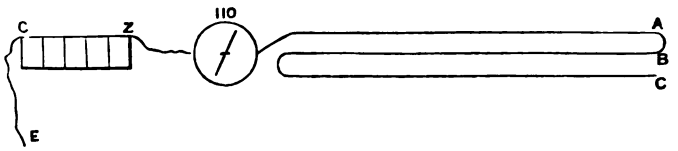
The wire	A	had a leakage	equal to	29
,,	B	,,	,,	30
,,	C	,,	,,	50
			Total leakage	109

The three wires when connected at the testing end and left free at the distant end, had a leakage of 110.



When looped so as to form one continuous wire, free at

the distant end, the leakage was still 110, or sensibly the same in each case.



The experiment was repeated and extended to other wires with a similar result.

224. In this case the resistance of the insulators was very great compared with that of the wire, as much as 80,000 units per mile, so that an increase in the distance of the points of leakage did not sensibly affect its amount.

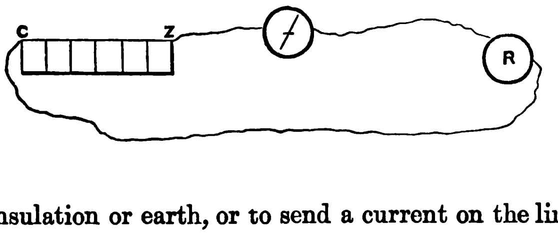
But when the insulation is so bad that the resistance of each support bears a nearer proportion to that of the wire between them, a thick wire will test worse than a thin wire, and a circuit of many instruments better than a direct circuit in which there are none except at the testing stations. For the same reason the fault called an "earth" will appear less as its distance from the testing station increases.

PART VII.

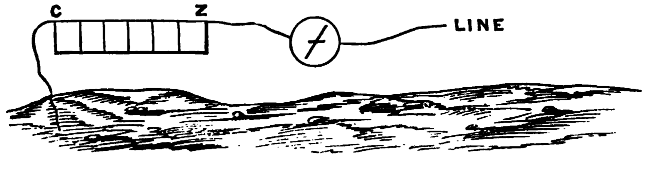
FAULTS,
AND THE METHODS OF DISCOVERING THEM.

225. Modes of connecting the wires for testing.

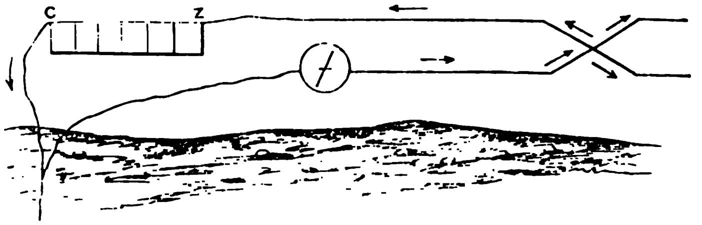
To test battery and detector on the standard coil.



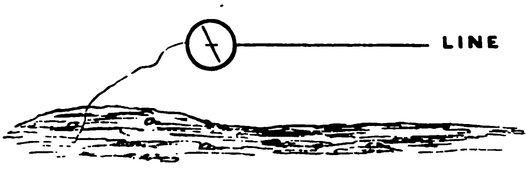
For insulation or earth, or to send a current on the line.



For contact between two wires.



To receive a current from another station.



Copper always to earth,
Zinc to line. (See 275.)

The faults of a circuit are the following:—

226. DISCONNECTION, or loss of continuity, when the circuit is *broken*, so that the current will not pass. The galvanometer needle does *not move* at all. (See 256.)

227. PARTIAL DISCONNECTION, when the resistance is *increased* by a rusty or badly soldered joint in the wire, dirt in the pivots of a key, or relay, &c. The *received* current is enfeebled, less current than usual leaves the sending station, and the needle or galvanometer *moves less strongly*.

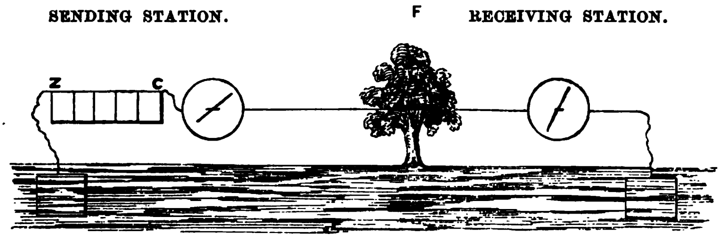
228. EARTH.—When the wire *touches the ground*, or some conductor in connection with the earth, such as a wet wall, a stay wire, &c., the current passing out from the sending station is always increased; the needle or galvanometer moves *more strongly* than usual, because the resistance of the circuit is *lessened* by an extra path being open to the current, which

splits between its own wire and the fault in the inverse ratio of their resistances (156).

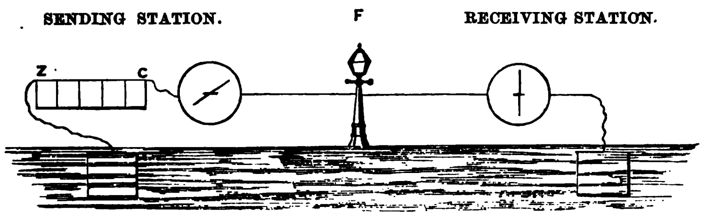
But the current received at the stations beyond the fault is *lessened,* because part is led away by the fault. Should the resistance of the fault be very much less than that of the circuit beyond it, so feeble a current will pass to the distant station, that the ordinary apparatus will not show it.

229. Partial Earth. — The current dividing at the fault F.

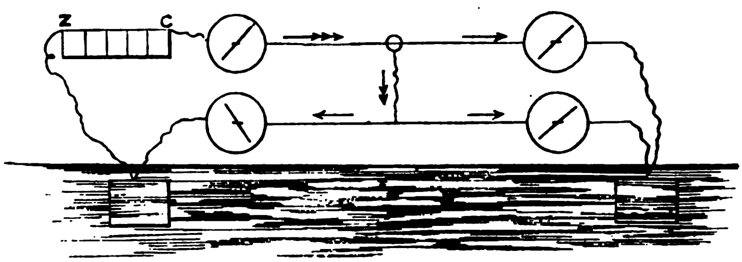
Signals weakened at receiving, strengthened at sending station.



230. Dead Earth.—All the current passing through the fault. Signals still stronger at sending station; no signal whatever beyond the fault.



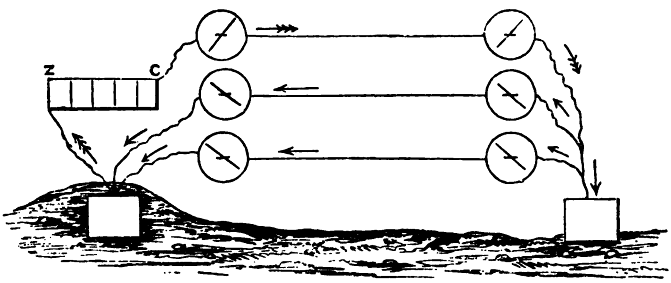
231. Contact. — When one wire touches another, the current divides at the fault between the three paths open to it.



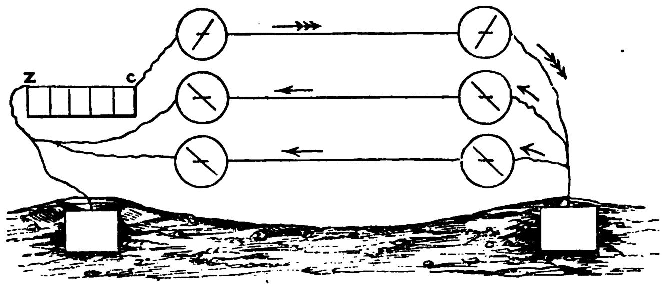
When a contact exists between two or more wires leading into the same office, if one of the instruments be worked, part of the current returns by the other wires, and causes their instruments to move also, but in a contrary direction. Another part goes on to the distant station by the wire on which it was originally sent, and the remainder to the distant stations by the wires in contact, moving the instruments connected with them in the same direction as that of the instrument on the original wire. (See p. 152.) In wet weather the dampness of the insulators enables part of the electricity to leak or escape from one wire to another, and to the earth. The current entering the other wires produces effects similar in appearance to, though less in amount than, those caused by actual metallic contact between the wires; hence this fault is called "*weather contact.*" It can be prevented by providing a good earth wire, so fixed as to intercept the current in its transit from one insulator to another, and convey it to the earth (149).

The signals at the *sending* station will appear stronger, while those at the *distant* end will be weakened, as in the case of partial earth (229).

232. Defective Earth.—When the earth wire or plate is defective, and offers a sensible resistance, a current sent on any one wire connected to it, splits between the earth and the other wires.



When it is totally disconnected, and there is "no earth at all," it divides entirely among the other wires connected to the earth wire, because it is usual to connect all the circuits of a station to one and the same earth wire, which is led to the earth plate.



In this last case no current will pass to the earth at all, even at the receiving end, because the earth forms no part of the circuit.

233. Thus whenever the earth is defective, all the wires will appear to be in *contact*. When the defect is small it may be mistaken for "weather contact," but the leakage from one wire to another, from damp, or want of insulation, is always *greatest in wet weather*, while the apparent contact from defective earth is *greatest in dry weather*, because damp increases the conducting power of the soil.

234. The remaining faults are, failure of battery, defective apparatus, and demagnetization.

235. When a circuit is interrupted, first make sure that the fault is not in your own office.—If a terminal station:

1. Ascertain whether a current leave your station or not, by pressing the key, and noticing if the needle or instrument moves.

2. If the needle does not move, put earth on at the test box; should it still remain unaffected, the fault is disconnection, or failure of battery in your own office.

3. If the needle is strongly deflected when the earth is on at the testing box, the fault is disconnection on the line, or at a distant station. Again:

236. Put a galvanometer in circuit at the test box between the instrument and line wires and move the key of your instrument.

1. If the needle moves more strongly than usual, the fault is probably earth on the line.

2. If it moves weakly, or not at all, there may be total or partial disconnection, either on the line or in the office; earth in the office, or a fault in the batteries.

237. Put earth on the galvanometer in place of the line.

If the needle now moves strongly, the fault is want of continuity on the line. If it still does not move, or moves weakly, there is a similar fault in the office.

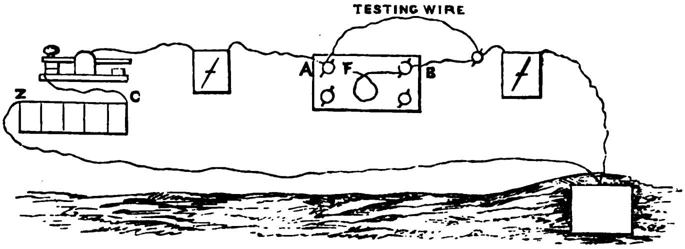
238. If the needle of your instrument, or the galvanometer attached to your printing machine, moves, while that of the test box galvanometer does not, there is earth between the two, the place of which may be found by disconnecting each part of the circuit successively, commencing at the test box.

When the wire which makes earth has been disconnected, the instrument needle will cease to move, because the circuit has been broken.

239. Should neither needle move, the batteries are out of order, or the circuit broken.

Try if the batteries produce a current, by putting a detector in circuit between the two poles.

240. Should the batteries be found in order, connect a piece of good wire to the instrument terminal of the test box, and with it touch successively the several connections and parts of the apparatus, commencing with the one nearest the test box. When the needle moves, the fault has been passed, and will be found between the point last touched and the one touched next before it.



Let the wire of the relay A F B be broken at F; touch the terminal B with the testing wire, the needle is unaffected. Touch A, and it moves, because the broken place has been bridged over.

241. If the batteries are faulty, they must be tested trough by trough, and cell by cell by a *quantity* detector (114), till the fault is discovered.

Remove the faulty battery, or connect it across with a wire.

242. Lacquer or dirt in the pivots of a key or relay will often cause disconnection, and especially at the stop upon which the key of a printing instrument lies, or the bridge which connects the springs of a needle instrument.

243. If best salad oil be applied to the pivots and points of contact of printing keys, the dirt will never harden sufficiently to break the connection. A film of oil secures a better contact than a dry surface.

244. It must be recollected that a strong current will pass an imperfect connection, while a weaker current would be stopped

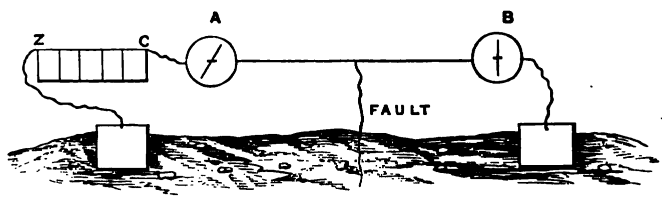
by it. Thus it frequently happens that a dirty key will transmit signals perfectly well when the circuit is shortened by putting earth on, when no current will be sent at all when the entire line is open.

246. In all tests for want of continuity, a very feeble current should be employed, because a strong current may pass an imperfect joint, and prevent it being discovered. Use one or two cells only.

247. If everything is right in the office:

Send a current from the test-box through the detector. Should the resistance of the wire be about the same as usual, and the needle move about as strongly as in the usual daily tests, the fault is *earth* at or very near the distant terminal station.

248. Should the needle be more strongly deflected than usual, the fault is nearer the testing station.



Suppose it to be between the stations A and B:

1. Let A disconnect the wire, and "say when done." The current will not pass now, because the earth is beyond A.

2. Let the wire be "joined up as usual" at A, and disconnected at B. Breaking the circuit at B will not affect the detector, because all, or almost all the current will go to earth at the fault, showing that B is *past* the fault.

249. Or get each station in succession to send you a current, and try if it reaches you. This method is not certain, as many persons can unscrew a wire, but are not to be depended on to send a current. Besides this—

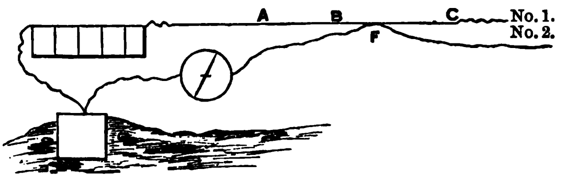
250. Disconnection and earth also are not always total.

A feeble current may reach you in cases where one is sent from a testing station, even when there is partial earth between that station and your own, or where there is partial disconnection (246).

251. If you have no means of speaking direct, send a message by some other route, instructing the station to disconnect or put earth on the wire at a certain time, for five (or fewer) minutes. Thus: "Disconnect —— circuit from 10.20 to 10.25, say if you will do so. Time 8.10."

The reply should be, "I will disconnect —— circuit from 10.20 to 10.25. Time 8.20."

252. CONTACT.—When a current sent on one wire returns by another, and moves the apparatus connected with it, disconnect both instrument wires at the test-box. Send a current on one of them, and place the galvanometer in the other, thus:



Let F be the fault, and A B C testing stations, the fault being between B and C, part of the current sent on No 1 wire will return by No. 2, and move the needle of the galvanometer attached to it.

Instruct station A to disconnect either of the two wires, and "say when done;" the deflection will cease, showing the fault to be beyond A. Instruct A to join up, and B to disconnect; the same result will follow.

But when C disconnects, the deflection will continue, showing that C is beyond the fault. Care must, of course, be taken not to be deceived by "wet contact," or the ordinary leakage of one wire into another.

253. *Never test for contact by having the earth put on at the*

testing stations; this method is liable to great error, and has led to much inconvenience.

If *a very good* earth be put on *beyond* the fault, and very near it, it will cause the contact to disappear almost entirely, because the resistance of this new path will be very much less than that of the other wire.

And if the earth be *imperfect,* and be put on between the original station and the fault (the near side of the fault), the contact will not disappear, especially if the wires be clean, so that the resistance of the points in contact be very little.

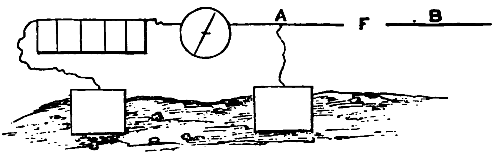
The fault may appear less, but unless care is taken that the testing battery be not strong enough to give a "*full deflection*" the variation in the resistance of the circuit may escape notice.

254. DISCONNECTION.—Want of continuity.

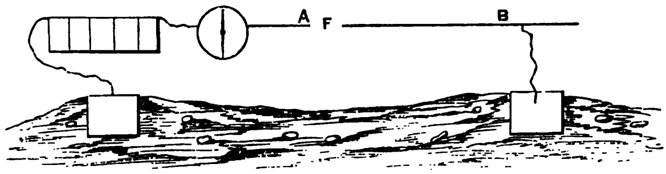
If, when a current is sent from the test-box to the line, the needle does not move, or moves feebly, there is total or partial loss of continuity. The resistance of the wire is increased in the second case, enfeebling the current, and the circuit is entirely broken in the first case, stopping the current altogether.

255. Suppose the disconnection to be total, and to lie between A and B.

Send a current to line through the detector, and instruct the nearest station to put earth on and "say when done." If the needle moves, the fault is beyond the station at which earth was put on.



Let the earth be taken off at the first station and put on at the next, and so on till the fault has been passed, when the needle will remain stationary as at first.



256. Except in very fine weather, it will be found that as the distance to which you test increases, more and more current passes out to line from the testing battery, because of the leakage at the supports; and if the daily testing of the wire for insulation (earth) has been duly registered, an approximate guess at the distance of the break may sometimes be made from the amount of earth on the wire.

257. In very fine weather, and on a very good line, the amount of return current received from the wire when a strong current is sent, and the line instantly put to earth through a galvanometer, will show if the fault be near or not. A printing machine shows the return current readily:— (see section 193).

258. Partial Disconnection.—Much greater care is required in testing for this fault.

Send a weak current on the line through the detector, and let earth be put on at each successive station as before, until two stations are found, at the nearer of which the earth makes a *great* difference, and at the more distant of which it makes a *very slight* difference in the deflection.

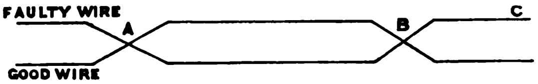
As some current passes the fault in each case, so much may pass even when the earth is put on *beyond* the fault as to deceive the tester, if a strong current be used.

259. Total Disconnection.—Each station along the line may be instructed in turn to send a current. If a current reaches you, the wire is perfect as far as the station which sends it.

But this method is liable to error from the want of care at the stations in circuit.

260. When a wire is broken, and lies on the ground, it some times, but rarely, tests as if partially disconnected, the soil conducting the current.

261. INTERMITTENT FAULTS.—When an intermittent fault does not continue long enough to be tested for, let the faulty wire be crossed at your station, and at another, with a good wire, thus :—



If the fault shifts to the other circuit, it will lie between A and B, the stations at which the wires are crossed.

If it remains on the same circuit as before, it is beyond B.

Let the wires be "crossed" at C, and "put straight" at B, and so on station by station till the fault shifts, when it will be found between the two stations at which the wires were last crossed.

To "cross" wires means to interchange them, as shown in the diagram.

To put wires "straight," is to restore them to their original places.

262. The foregoing are the methods of testing from a terminal station. When it is required to test from an intermediate station, the first step is to put the earth on, first on one side the apparatus, then on the other, in order to find which section is defective. So long as the earth is on, the station is, in fact, terminal, and the previous rules apply.

263. When the section of the line in which the fault lies has been determined by the preceding methods, it can

ordinarily be found by the lineman. But should it not be visible, it must be tested for on the line, thus:—

264. To test for earth:

Let an Inspector put a current on at the station, and walk out on the line with a galvanometer, after having disconnected the wire at the other end. Let the detector be placed between wire and earth; if the current passes, the fault will be still farther distant. This test must be repeated at different points until the current ceases, or greatly diminishes. If the weather and the insulation be bad, allowance must be made for the gradual weakening of the current, caused by the leakage at the posts.

When the fault is passed, the current will either cease altogether or be very much weakened.

If the galvanometer offers but a slight resistance, sufficient current may pass by it to deflect the needle, even after the fault has been passed. It is desirable, therefore, to make the resistance of the detector greater than that of the line to be tested.

Or the Inspector may take a small battery on the line, after having insulated the section at both ends; he can then disconnect at any convenient place, and test both ways.

265. Disconnection may be tested for in a similar way, by putting earth on at both ends of the wire, instead of disconnecting it; or a current may be put on at the station and sought for with a detector, as in the previous case, taking the precaution to insulate the distant end of the wire lest another station interfere with the tests.

266. Testing by Time.—The Inspector may arrange with the clerk in charge of a station to test at certain fixed times and can disconnect or put earth on at various parts of the line.

267. Testing Covered Wires.—Covered wire should

always be very carefully tested, both for insulation and continuity, before it is used. It is not often that continuity fails, but now and then a wire will be broken inside the gutta percha. It may convey a signal, but will give more resistance than it should do, and in time will fail altogether.

268. It is useless to test for insulation *until the wire has been soaked in water twelve hours,* to give the water time to enter any small pinhole or crack which may exist. It should be tested with not less than 70 cells, if a vertical detector be used, and contact made and broken.* The Gutta Percha Company test their wire with a very good battery of 512 cells, and a very sensitive horizontal galvanometer. A small fault, if allowed to remain, will increase, and ultimately spoil the wire.

269. The wire may be *charged statically* by a battery (193) and the time noted during which it will retain the charge. Put one pole of the battery to the earth, and with the other pole touch one end of the wire for a moment. After, say 10 seconds, put the wire to earth through a galvanometer, when the charge will pass to earth, moving the needle. A good wire will retain the charge several minutes. If a galvanometer be not at hand, the charge may be taken on the tongue with equal certainty as to the result, and without any inconvenience from lengths under a mile.

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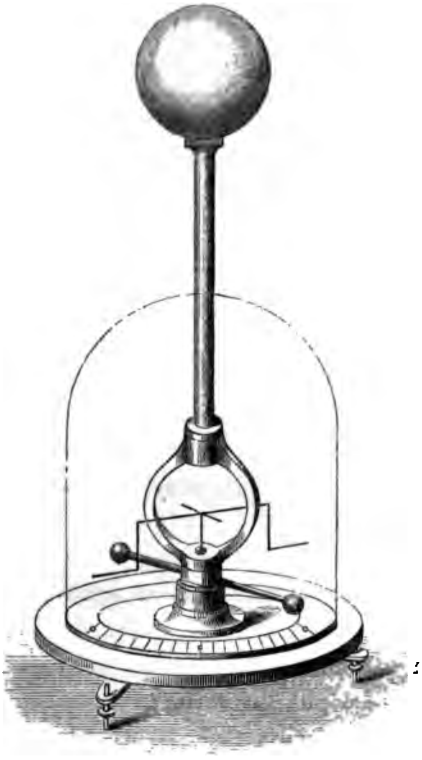
* *Making and breaking contact.* A very feeble force frequently repeated will set a needle swinging, when the movement caused by a single contact is imperceptible. But care must be taken to make the contacts coincide with the swing of the needle, so as to assist it.

The use of a horizontal needle would be very tedious were it not easy to check its swinging by making and breaking contact, so as to make the current oppose instead of aid it. The application of a feeble magnet, such as a penknife, will produce the same result.

This test will not succeed with lengths of less than half a mile, unless a very delicate galvanometer be used; with the tongue, lengths of 100 yards may be safely tested.

270. Or the wire may be connected to a Peltier electrometer and charged. If the insulation be good the needle will diverge, and remain diverged for a time, varying with the insulation. Note the time the charge is falling from full to half charge.



271. It is essential in these statical tests that the end of the wire be clean and very dry. The coating at the end

should be carefully washed with turpentine, or paraffin oil, to prevent conduction over its surface.

272. It is always necessary to use a strong current and a delicate detector in testing new work, to ensure its being perfect. A small power is not always sufficient to discover a fault in covered wire. In very wet weather 48 cells and a vertical detector may suffice, but in ordinary weather a horizontal detector should always be used, or a powerful battery of not less than 70 cells, because many faults will nearly disappear when the covering is tolerably dry. The more delicate the galvanometer, the fewer batteries need be carried on the line.

273. In a tunnel the place of a fault may be found thus:— Put a current of 40 cells, or more, upon the wire at the mouth of the tunnel, disconnecting the other end. Wrap one bare end of a piece of covered wire with wet cotton waste, and connect the other to a detector in connection with the rail. Run the waste along the wire, carrying the detector forward until the needle is deflected by the current escaping through the waste at the fault. The detector may be fixed to a staff ending in an iron point, which can be set upon the rails, which should be moistened to make good earth. The wire may also be cut and tested in sections.

274. If the covering is found, on inspection, to be injured or decomposed, the wire should be removed and repaired in the open air.

275. In all tests of covered wire, the copper pole of the battery should be put to earth, so as to send a negative or zinc current to the wire. For positive currents have a tendency to expel damp from the fault, negative currents to increase it. The copper current oxidizes the bare part of the wire, and coats it with an imperfect conductor, while the zinc

current reduces any metallic salts that may have been formed, and, as it were, electrotypes a clean surface.

Thus, an underground wire often seems perfect if tested with a copper current, which will give a large amount of earth to a zinc current.

276. When a wire is too defective to be used, while the fault is too small to be readily found by distance tests (280), it may be made worse by keeping a powerful zinc current upon it for several hours.

277. And a bad wire may be made better for a time by a copper current, taking care, if reversed currents are employed in signalling, that the zinc or reverse current shall be much feebler than the copper or sending current; but the copper current will, however, eat away the wire sooner or later.

278. In tunnels where a fault is exposed to dropping water charged with salts of lime, the wire is frequently eaten away for a $\frac{1}{4}$ inch, the current still passing by the conducting power of the salt of copper formed, so long as the tunnel is wet. Hence sometimes such a wire works best in very wet weather. Iron wires are sometimes corroded by water dripping through limestone rock.

279. When a powerful battery is employed for signalling, there is great danger of injury to wires covered with gutta percha or rubber. Hence the necessity for using a few large cells rather than numerous small cells when equally good signals can be produced by either (176).

280. Testing for the Distance of Earth or Contact.—The principles upon which the tests are founded are :—

1. When a current is sent upon a faulty wire, it splits at the fault between it and the rest of the circuit beyond it.

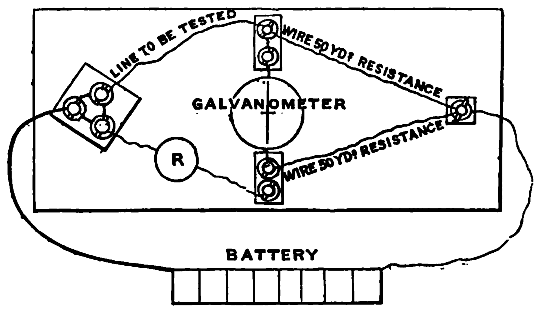
2. The amount of deflection of a galvanometer is a measure of the resistance of the circuit on which it is placed.

281. The apparatus used is—

The galvanometer, or
The differential galvanometer, or
The Wheatstone's "bridge," and
The resistance coils.

282. The *galvanometer* must be very delicate; a horizontal needle suspended on an agate cup is preferable.

283. *Wheatstone's bridge.*



If the resistance coils R and the line be exactly equal, the battery current will be equally divided between the two sets of wires, and its action on the galvanometer will be exactly balanced, so that the needle will not be affected.

But if there be a difference between the resistance of the coils and of the line, a portion of the current will pass through the shorter wire, and move the needle.

The line being attached in its place, resistance is added by the coils till the needle cannot be moved by making and breaking battery contact.

The resistance added is then equal to that of the line under test.

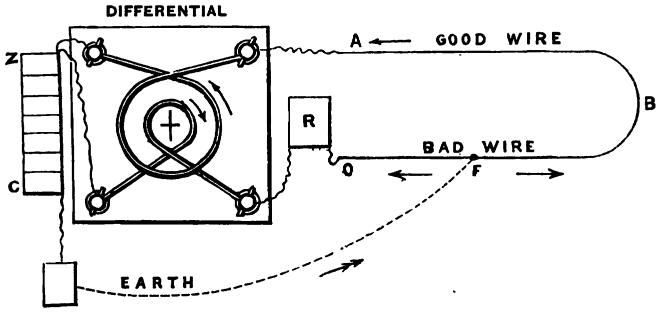
284. As no two samples of wire conduct precisely alike, it is necessary to learn the resistance of every circuit in miles (or units) of the standard resistance coils. This can be deduced from the daily testings in the case of line wires, and

from the record of its testing before it was laid, in the case of a cable or underground wire.

285. The following is the most accurate system of testing for the distance of an earth, in cases where a wire is available to form a loop with the faulty wire, so as to bring both ends of the circuit into the office :—

Choose a good wire, one free from fault, and similar to the wire to be tested. Insulate both from earth at the nearest available point beyond the fault, and connect them together there in a loop.

Let A B be the perfect wire and O B the faulty one, connected together at B, the fault being an earth at F.



Put the copper pole of the battery to earth.

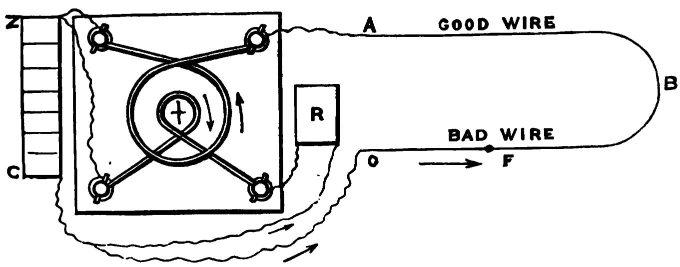
Connect the zinc to the terminal of one of the coils of the differential, and also to the opposite terminal of the other coil, by a short and thick wire.

Connect the perfect wire A B to the unoccupied terminal of one of the coils.

The current will enter the wire by the fault, through the earth, and will move the needle.

Place the resistance coils R between the faulty wire and the remaining terminal of the differential, the current will now divide at the fault F; and as the distance from O to F is less than that from A to F, the current in O F will overcome that in

A B F, and move the needle in the opposite direction. Resistance must be added to O F at R until the needle no longer moves when contact is made and broken repeatedly with the battery wire Z. The resistance R O F will now be equal to A B F. Note this resistance, and if the resistance of the wire when perfect be not previously known, find it thus:—



Take off the earth, connect one end of the loop to the battery, the other end to one wire of the differential. Connect the same pole of the battery to the resistance coils, the other end of the coils to the opposite end of the other wire of the differential, and the other pole of the battery to both the unoccupied terminals of the galvanometer. Add resistance till the needle is balanced: the amount added will be the resistance of the loop.

Then this resistance, less the resistance added to the faulty wire to balance the needle, and divided by two, is the resistance of the piece O F.

Thus, supposing the resistance of the loop to be 100 units, and that 10 units have been added to the faulty wire to balance the needle,

Then $\frac{100-10}{2}=45$ units, the resistance of the faulty wire between the galvanometer and the fault.

If the unit of resistance exactly equal one mile of the wire tested, which will very seldom be the case, the 45 units will be 45 statute miles of that wire; but should the actual length of the loop not agree with its resistance, the units must be reduced into miles by direct proportion.

Say that the loop of 100 units measures 120 miles, then by proportion,

If 100 units equal 120 miles, 45 units will equal 54 miles,

$$\frac{120 \times 45}{100} = 54.$$

If the circuit include covered wire or an instrument, allowance must be made for their resistance.

No two samples of iron or copper wire agree exactly in conducting power, or even in gauge; the resistance of each part of the circuit should therefore be ascertained if possible; but a mile of tunnel or other percha wire may roughly be taken as giving double the resistance of the same length of No. 8 iron.

286. The following method of testing for earth may be adopted when a return wire is not available. It is, however, not as accurate as the former method. Shorten the length to be tested as much as possible, and let all the instruments in circuit be taken out.

1. Let the wire be *disconnected* at the first station beyond the fault; measure its resistance.

2. Let it be *put to earth* at the same station, again measure the resistance, which will be less than before, because there are now two roads open to the current, viz., the fault, and the wire beyond the fault.

3. Subtract the second resistance from the first.

4. Subtract the resistance when put to earth (2) from that of the wire when in good order.

5. Multiply these two remainders (3 and 4) together, and

extract the square root of their product. Subtract this square root from the resistance when put to earth (2), and the remainder will be the resistance of the wire between the testing station and the fault.

For example: Suppose there is a partial earth on a line whose resistance when in good order is 28 units;

1. And that the resistance when disconnected	=	40 units.
2. When put to earth	=	24 „
3. Difference	=	16
4. And the difference between 24 and 28 is	=	4
5. The two remainders multiplied ...	=	64

The square root of 64 is 8 ($8 \times 8 = 64$), which, deducted from the resistance when put to earth, leaves 16 units as the resistance of the wire between you and the fault.

A contact may be tested for in the same manner, for it matters not whether the leakage takes place through another wire or to the earth direct.

287. When there is *dead earth*, that is a fault offering *no resistance*, the wire will test precisely the same whether disconnected or not, and its resistance will give the distance of the fault at once.

288. And if the *contact* be perfect, as is the case when two clean wires are twisted together, *half* the resistance of the *loop* will, of course, be the distance of the point at which they are connected, provided both wires are equal in conductibility. But it can never be known with certainty whether the point of contact offers resistance or not. Section 285 gives the most certain results.

289. When a contact occurs between the two wires of a

branch line, it will appear like an earth to the stations upon the branch, while the other stations would report inattention at branch stations, because they would be able to speak to all stations except those on the branch.

290. Constant Current.—When a wire comes in contact with a bell wire or block signal circuit, used at intervals, a current will be sent upon it whenever the signal is used, and the locality of the fault will be known to a person acquainted with the line.

PART VIII.

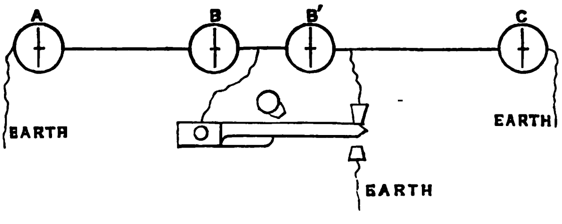
SIGNAL APPARATUS:

SWITCHES, COMMUTATORS, OR TURNPLATES.

291. These are employed for connecting one circuit to another, for dividing a circuit, or for any purpose where connections have to be altered.

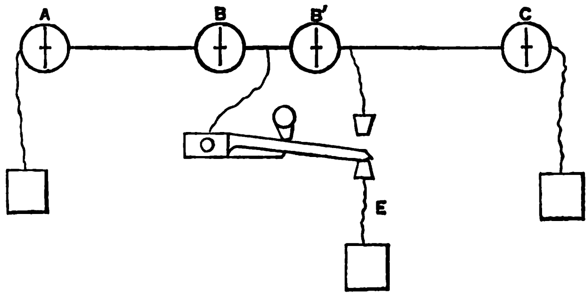
292. In the *lever switch* a lever or spring is removed from one stop to another by a pin projecting from a movable axis, or the pin places the axis itself in connection with the lever or spring.

Thus, suppose it to be required to divide the circuit A B C at the central station B, so as to enable each half to be worked independently,



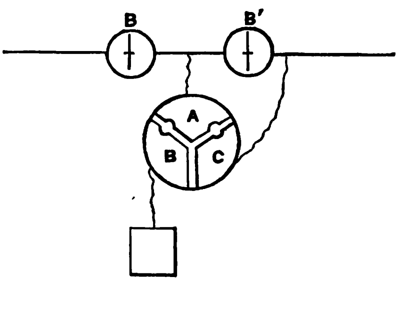
1. In this position of the switch a signal will pass through

the entire circuit, with the exception of the second instrument, at B (viz. B′), which is unnecessary, hence it is connected across, or placed on *short circuit.*



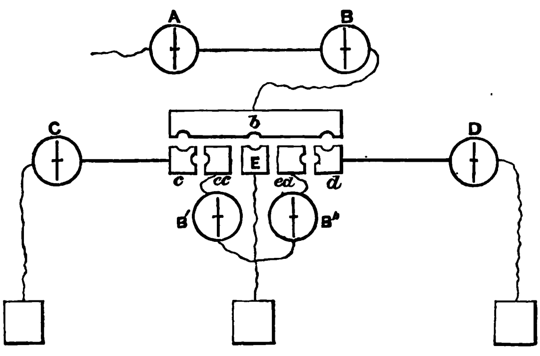
2. In this position of the switch the earth is put on between the two instruments at B, and the instrument B′ is thrown into circuit. The two parts of the line can now be worked independently.

293. With a peg switch the arrangement would be :—



1. The peg placed between A and C.
2. The peg placed between A and B.

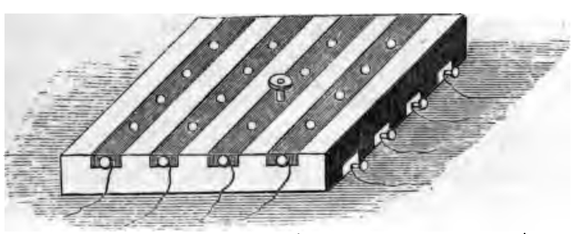
294. If it be required to enable A to work through B to C, as in case 1; to a fourth station on a separate wire, D; or to make the three lines A B, B′ C, B″ D, independent.



1. A through B to C, D and B″ forming a separate circuit. Pegs connecting *b* and *c*, *d* and *ed*.
2. A through B to D, B′ and C forming a separate circuit. Pegs connecting *b* and *d*, *c* and *ec*.
3. Each circuit separate, *i.e.*, A to B, C to B′, D to B″. Pegs connecting *b* and E, *c* and *ec*, *d* and *ed*.

The same changes may be effected with a switch of three levers.

295. The Swiss "Commutator," or "Universal Switch," enables us to connect any two circuits.

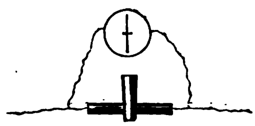


Plates of brass are let into the opposite sides of a piece of wood, crossing each other and insulated. There may be as many plates as there are circuits to be connected with one another.

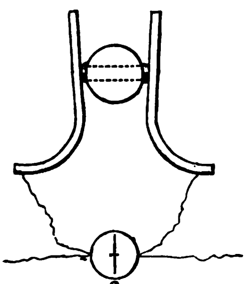
The peg, P, fits tightly in the upper set of holes, and spring-tight in the lower set.

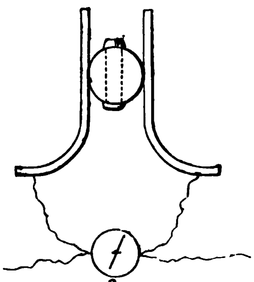
296. The peg switch allows of the greatest number of combinations, and is the cheapest; but the lever switch is more readily manipulated, and is not so liable to be *left wrong* carelessly.

297. It is sometimes required to cut an instrument or bell out of circuit: the arrangement is this—



1





2 3

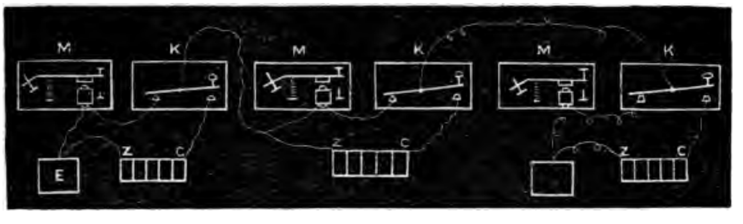
When the peg is placed in the hole as in fig. 1, or when the barrel is turned in the position shown in fig. 2, so as to connect the two springs metallically, no current will pass through the galvanometer, because its resistance is infinitely greater than that of the switch (156). If the peg is removed, or the barrel turned into position 3, the short circuit is broken and the current passes through the coil. A switch of this kind attached to an alarum is called a "*silent.*"

PRINTING TELEGRAPHS.

298. THE MORSE APPARATUS consists of a key for sending the current, and an electro-magnet, the armature of which is fixed to a lever carrying a point or style, which imprints a mark upon a band of paper carried forward by wheelwork.

The electro-magnet attracts its armature as long as a current is made to flow through the wire with which it is wound, and ceases to attract it as soon as the current is cut off by breaking battery contact with the key; the armature is then drawn back by a spring. The paper is carried forward by two rollers, in the uppermost of which there is a groove to receive the point of the style.

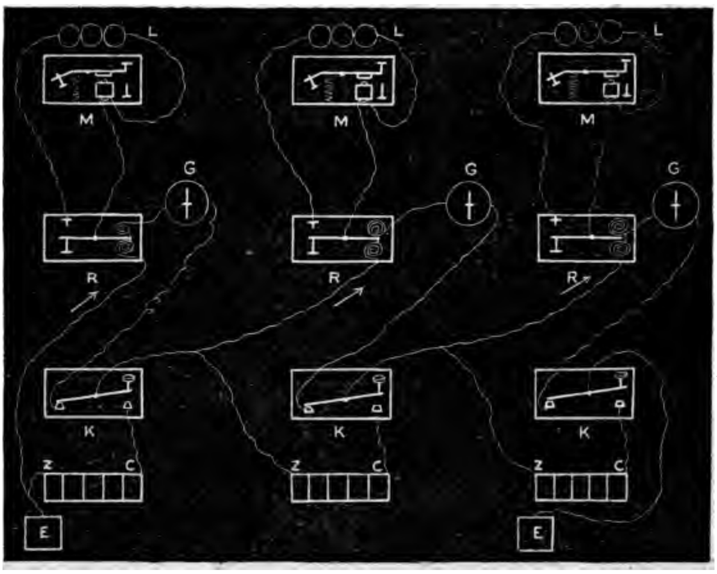
299. If the circuit is short, the electro-magnet may be acted on by the line current itself, and should be wound with a moderately fine wire, so as to *multiply* the effect of the current.



THREE STATIONS WORKING WITH LINE CURRENT.

When the circuit is long, and the current consequently weak, it is made to act upon a *relay* (305), an apparatus capable of being moved by a feeble current, which completes

a circuit, consisting of the Morse instrument, and as powerful a *local battery* as may be found necessary, thus—



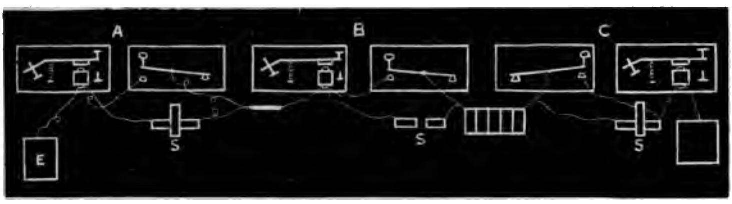
THREE STATIONS WORKING BY RELAYS.

M is the Morse, K the key for sending the current, R the relay, G the galvanometer, L the *local* and Z C the *line* battery, E the earth plate.

If the coils of the electro-magnet are wound with a somewhat thick wire, as No. 24, a few cells, say six, will suffice for the "local," but they must be *at least* twice as large as those used for a line battery. If a thinner wire, as No. 30, be used, ten or twelve cells of the line battery will suffice, and as the armature is made of soft iron, which is attracted independently of the direction of the current, it does not matter in which direction the current is made to flow through the coils.

300. On a circuit not exceeding twenty miles of line wire, three or more Morses, A, B and C, may be worked by a single set of batteries, thus :

The sending keys at the several stations are so arranged that when they are at rest the circuit is complete, and a constant current flows through the whole of the instruments, attracting their armatures ; so that, if the paper be allowed to run forward, a continuous line will be marked on it. By opening a switch attached to the keys the circuit is broken, and the break or gap thus made can be again filled by pressing the key. Thus, if any station opens its switch the current ceases, and all the armatures are released ; if this same station presses its key the circuit is again completed, and the armatures are attracted.



S S S are the switches. The switch at B is opened ready for sending by the removal of the peg, and by pressing B's key the circuit will be completed and a signal sent.

The best position for the batteries is the central station of the group.

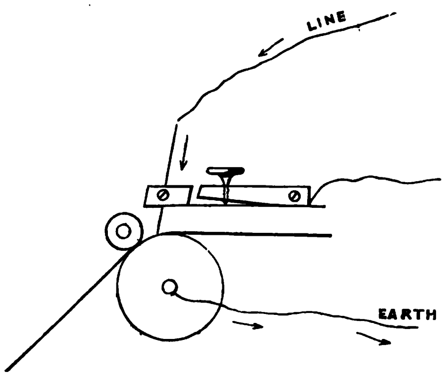
The Bain Printing Machine.

301. When a current passes through a solution of any chemical compound it decomposes it (29).

If two wires, not touching each other, are placed in the solution of a salt, when a current is sent through them and the liquid, that wire which is connected with the copper of

the battery is dissolved, or made to combine with the acid, while the wire connected with the zinc is not dissolved (31), but the metal or alkali of the salt is deposited upon it.

In Bain's apparatus a strip of paper is soaked in a compound which is readily decomposed.



This strip is carried forward by wheelwork, and is made to pass under a pencil of iron wire connected to the line wire, or to a relay, in such a manner that the positive or copper current passes *from the wire to the paper*, and through the paper to the metallic wheel of the apparatus which moves it forward.

When a current is sent on the wire, the solution with which the paper is soaked is decomposed; the iron pencil is dissolved and forms Prussian blue, leaving a blue mark on the paper.

302. The solution is a mixture of yellow prussiate of potass (ferrocyanide of potassium) and nitrate of ammonia. It is made thus:—

Place a sufficient quantity of good nitric acid in a wide pan of glass or stoneware, and throw into it lumps of ordinary carbonate of ammonia until it ceases to effervesce, taking care that too much is not put in at once so as to make the effer-

vescence too violent, and that enough is added to leave some undissolved after the acid is saturated, for it is necessary to have a little free ammonia (*i. e.* ammonia not combined with nitric acid) in the liquid. This liquid will be solution of nitrate of ammonia.

The solution of ferrocyanide of potassium is made by dissolving as much of that substance as the water will take up, making a saturated solution. Mix equal parts of each solution with a quantity of water equal to the two together —one part of each solution to two parts of water.

It is better to mix only as much as will last two or three days. The separate solutions will keep any length of time, but they do not keep so well if mixed. The prepared paper should be preserved in a covered jar, in order that it may not become dry, and it must not be used too moist.

It should always be prepared five or six hours before it is wanted for use.

Nitrate of lime can be used instead of nitrate of ammonia; it is made in a similar way and is very much cheaper.

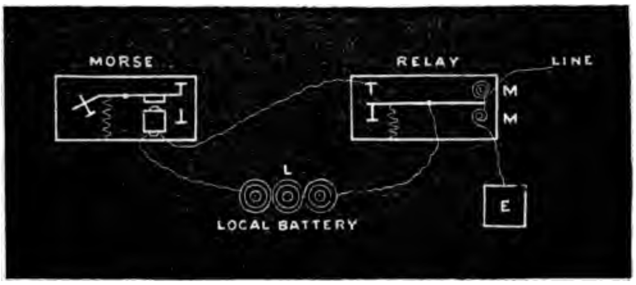
303. On short lines the *line current* (current from the sending station) is sufficiently powerful to decompose the solution, but on long lines it is necessary to employ a local current from a relay. The local battery should consist of 18 to 24 cells of an ordinary line battery.

304. Care must be taken to keep the wheel over which the paper runs quite clean, or the current will not pass freely. A little dilute ammonia readily dissolves the compound of copper which is formed upon the wheel.

This wheel and all other pieces of metal exposed to the action of the paper or the solution should be tinned, as the liquid has no action on tin, while it rapidly dissolves copper or brass.

305. Relays.—In whatever manner a relay may be con-

structed its principle is the same. It consists of a bar either of soft iron or of magnetized steel, fixed so as to be free to move when acted on by an electro-magnet or coil.



The wire of the electro-magnet or coil M M, is placed in the line circuit; the bar is connected with one pole of the local battery L; a pin or stop, fixed near the bar, is connected to one end of the Morse machine coil, and the other end of this coil to the other pole of the local battery.

When no current is passing on the line, the bar is held away from the stop by a spring or other means, so as to *break the local circuit;* when a current is sent on the line, the bar moves towards and touches the stop, so as to complete a circuit composed of the printing machine and a local battery.

Immediately the current ceases in the line wire, the bar flies back and again breaks the local circuit.

306. In the case of a relay consisting of an electro-magnet with a soft iron armature, the first effect of reversing the current after the armature has been attracted, is to *repel* it; but almost immediately after it is *reattracted.*

Although soft iron loses its magnetism very rapidly, yet it retains it for a short time after the current ceases, so that the armature retains the polarity impressed upon it by the electro-magnet, for a moment after the poles of the electro-

magnet have been reversed. So long as the armature retains this polarity it is repelled by the reversed current, but as soon as a fresh polarity is given it, it is again attracted. Thus, if the key by which the signals are sent on the line be arranged so as to give a very short reversal of the current after each signal, the armature will be repelled, and will be prevented sticking, as it will sometimes do, especially if it be allowed to touch the core of the electro-magnet (67).

A very much less powerful spring will be required to break the battery contact, and therefore a less powerful current will suffice to give the signals.

307. A still more sensitive relay may be constructed by abandoning the spring altogether, and trusting to the reversal of the current both for removing the bar from the battery contact and for holding it back, between each successive signal. The current will now have still less work to do, not having to overcome the resistance of the spring, but in this case the movable bar or armature must be a permanent magnet, the direction of whose motion will be reversed by a reversal of the current, in a similar manner to the needle of a galvanometer.

The key is so arranged, that during the transmission of a message a current is *constantly* sent on line; in the one direction to move the relay into the position of battery contact, and in the other direction to remove it from that position and hold it back.

308. There is a very great advantage in the method of reversed currents. It is possible to work through a large amount of leakage from other wires. Should the current leaking into the wire be in the same direction as the reversed current, it assists it in holding the bar back. Should it be in the direction of the direct or printing current, it will not move the relay, unless it is powerful enough to neutralise the reversed current.

In the method of working by single (non-reversed) currents, there is a limit to the degree of delicacy of the relay, because if very sensitive it will be acted on by all the small leakages from the other circuits near it, and will print false signals. But when reversed currents are employed there is no such limit, and an instrument delicate enough to record the leakage from other wires will yet print accurately whatever is sent on its own proper wire, the reversed current shutting out as it were, or neutralising, any leakage which may escape into the wire during the intervals between the signals.

Reversals are absolutely necessary when underground or submarine wires are used (203), and also where great rapidity of signalling is required, for the purpose of discharging the wire.

309. In order to increase the power of permanently magnetized armatures and to lessen their liability to lose their polarity, they are frequently magnetized by the induction of a large magnet placed in contact with or near them (72).

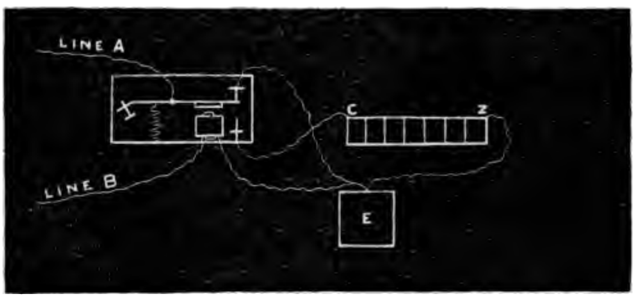
310. When permanently magnetized armatures or bars are used, the line current must be made to pass in one and the same direction through the coils of each relay in the circuit, and the same rules must be observed as in connecting up a series of needle instruments (325).

311. When working with reversals, if the line current is very weak there is a great advantage in giving the bar of the relay a tendency to rest against the battery contact stop instead of upon the insulated stop, keeping the local current always on. It requires a certain force to *make* perfect contact, but very much less to *break contact*. Thus, when signals are weak the current may have power enough, when reversed, just to remove the bar from the battery stop, so as to *break contact*, when it would not be able to press them sufficiently firmly together to *make contact* unless aided by the tendency

given to the bar, far less to move it through the space between the stops. Care must be taken not to leave the batteries thus on *short circuit* when the instrument is not in use, as it would weaken them seriously.

312. TRANSLATION.—When a circuit exceeds a certain length, the line current becomes very much enfeebled in wet weather from leakages, so that either a very large battery is required at the sending stations, or signals will not pass at all.

313. Messages between very distant stations are frequently read off at an intermediate station, and *transmitted* by a second clerk. This duty can be performed automatically by a *translator* or *automaton clerk.* The principle of translation (carrying beyond or forward) is to cause a relay to complete the circuit between a battery and a second *line wire,* in the same manner as that in which the local circuit is completed between the battery and the Morse (299). The simplest form of translator is the Morse lever itself.



Let the two screws which limit the movement of the Morse lever be insulated from each other and from the lever itself. Let the line wire to which the message is to be translated be connected to the lever; the earth to that screw on which the lever lies when at rest; one pole of the translating

battery to the screw to which the lever is attracted when a signal is being received, and the other pole to the earth.

When the Morse is not being worked the lever puts the wire A to earth. When a signal is received through B, the lever is made to touch the stop or screw connected to the battery, so that the line wire A is disconnected from the earth and placed in contact with the battery. The signal received on the Morse through the wire B is thus *sent forward* (translated) *to* A. By a chain of such arrangements signals may be sent automatically to any distance.

314. By arranging in a similar way the machine connected to the line *to* which the signal is to be translated, it will itself translate from that second line to the first, and the two distant stations can correspond through the medium of the intermediate one.

315. And signals may be made to *radiate* from the intermediate office to the several circuits in connection with it by means of their respective Morse levers.

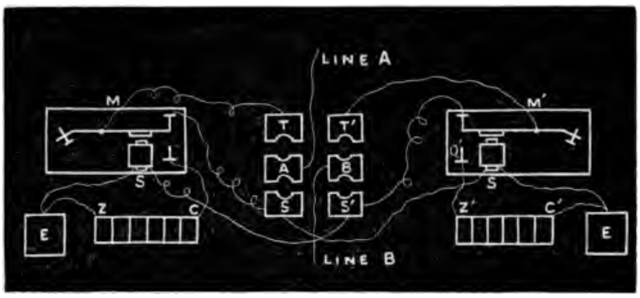
316. In order to enable the several circuits connected for translation to be worked separately if necessary, a switching arrangement is required, which is shown by the diagram on the following page.

For the sake of simplicity the Morse machines M M′ are supposed to be worked by the line current.

If a relay is used, the wires here shown as connected to the coils of the Morse will go to the relay.

The six insulated metal plates T A S, T′ B S′, fixed on a board, form the switch. The plates A and B are connected to the line wires A and B respectively. When the two circuits are to be connected for translation, metal pegs are placed between A and T and B and T′, so that a current arriving by the line wire A to the plate A of the switch passes by the metal peg from A to T, then by the connecting wire to the lever

of machine M, through the lever to the stop on which it rests, thence by the connecting wire to plate S, which is insulated, so that it cannot pass, except by the branch wire to the electro-magnet of machine M′ and thence to earth, moving the lever of M′ to the stop Q′, completing the circuit between the battery Z′ C′ and the line wire B through the lever of M′, the plate T′ and the peg inserted between T′ and B. If a current be received by line wire B, a similar series of operations will occur, translating the current to the line wire A.

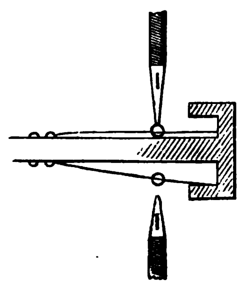


But if the pegs are placed between A and S and B and S′ respectively, a current arriving by A will pass to S; two routes are now open to it, one by the stop and lever of machine M to the plate T, which is now insulated; the other by the branch wire leading to the electro-magnet of M′, by which it will pass so as to move machine M′, whose lever will touch the stop Q′, but will not complete the circuit with the battery Z′ C′, because the plate T′, to which the wire connected to the lever leads, is now insulated. Thus the current simply moves its machine and is not sent forward. The same occurs when a current reaches the other apparatus by its line wire, and thus both circuits are independent, *the earth being put on* between them.

317. It is best to arrange that the current sent by the lever of the translator shall be furnished by the batteries connected to the key, so that it may be the same whether sent by hand or by the machine.

318. The bearings of the Morse lever and all the points of contact must be carefully kept clean.

319. A spring fixed to the lever (as in the figure) prolongs the contact and materially assists the signals.



320. A translator is frequently arranged to forward reversals, with the advantages mentioned in paragraph 308.

321. In all keys, relays and other apparatus for sending currents, there is very great advantage in a rubbing contact over a mere blow, and when there is a great loss from leakage on the line it is most advantageous to prolong the contact by a spring (209).

322. TRANSMISSION BY TWO STATIONS AT THE SAME TIME UPON A SINGLE WIRE.

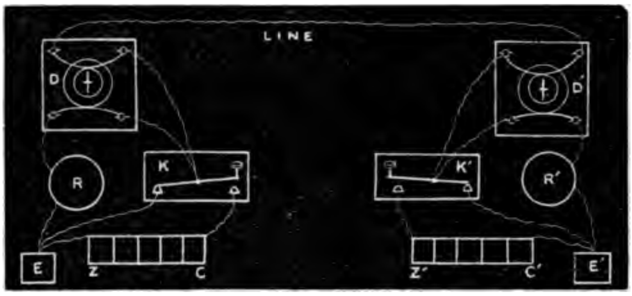
The principle of this method of signalling is this:—

Let D and D′ be differential galvanometers at the opposite ends of the circuit, one of whose pair of coils is connected to the keys at K K′ and the line wire, the other coil to the keys and through the rheostats R R′ to the earth E E′.

The rheostats are adjusted from time to time so that their resistance shall be exactly equal to that of the line wire.

When a current is sent by the key K it splits or divides into two equal portions, each of which takes an opposite direction through the differential D, and whose effects on the

needle are exactly balanced, so that it remains at rest; one portion traverses the rheostat R to earth, the other follows the line wire to D′, passes round the coil to K′, and there again divides between the direct route to the earth through the key, and that through the other coil of the galvanometer and the rheostat R′, the latter current being extremely feeble. The needle D′ moves and records a signal.



If while this is taking place the key K′ is pressed, the current will split equally between the coils of the differential D′, and its action on the needle being equally balanced it will not interfere with the received signal.

That portion of the current which passes to the line wire will either assist or oppose the current proceeding from K, and will in both cases disturb the equilibrium in the differential D, recording a signal at that station.

When the resistance of the line wire varies, from rain or other causes, the rheostat must be altered so as to restore the equilibrium of the *outgoing* current in the coils of the galvanometer.

323. *The principal faults to which the Morse apparatus is liable are the following:—*

1. Whatever tends to make the running of the paper irregular is apt to shorten dashes into dots, or to cause dots to

be lost altogether. This happens when the style is adjusted so as to mark the paper too deeply, when the paper sticks in the guides from irregularity in width, and when it does not run freely from the drum on which it is held.

2. If the style is not so adjusted as to move freely in the groove in the upper friction wheel, the signals will fail more or less; and if it is so much on one side as to be completely out of the groove, no marks at all will be produced. These faults generally arise from too much end play in the pivots of the lever, or from their working loose.

3. When the lever works too loosely in its bearings, irregular dashes, too deep at their commencement, but tapering off to nothing, are produced. When the armature is first attracted, the style indents the paper, but the forward motion of the band causes the lever to recede in its bearings until the style ceases to mark.

4. If the armature were allowed to touch the iron core of the electro-magnet it would "stick" or remain attracted, because the magnetism caused by the current does not cease when the current is cut off if the poles of the electro-magnet are connected by a piece of soft iron. The screw stop must therefore be so adjusted as to prevent the armature going too near the poles of the electro-magnet.

5. There is another screw to regulate the distance at which the armature shall remain when not in action, and a spring to pull back the armature against this *back stop* after each signal. The spring must be adjusted to suit the strength of the current, and the weaker the current the nearer must the armature be allowed to approach the electro-magnet.

6. The attraction decreases very rapidly with the distance through which it has to act, so that the nearer the armature is, the more powerful the attraction.

7. But it must never be allowed to touch, and if the current is so feeble that the screw stop cannot be used, a piece of writing paper laid over the poles of the electro-magnet will prevent sticking, and at the same time permit the armature to approach as closely as possible.

8. Signals are reversed, or the spaces between signals printed instead of the signals themselves, when the current flows in the wrong direction through the relay, so as to complete the local circuit by the *reversed* instead of the *direct* current, and the marks on the paper will frequently be dots only. To remedy this fault the wires of the relay, or the batteries of the sending station, must be reversed.

9. When marks are confused, the relay requires adjustment to suit the strength of the current.

10. If the line current moves the *relay*, but not the Morse *machine*, the fault will be in the local circuit, dirt on the relay, contact from a broken wire, a loose connection, or a faulty cell in the local battery. If the machine does not print when the relay contact is made with the finger, the local circuit is certainly defective.

11. When communication is interrupted, the sending batteries and apparatus should be tested on *short circuit* by connecting together the terminals leading to earth and line, or up and down line respectively, and moving the key. If the batteries, key, and connections, be in order, the machine should move, for the line is now cut out of circuit, and is replaced by the wire used to put the apparatus on short circuit.

12. It must be borne in mind that the local battery being placed on a circuit of feeble resistance, will consume much more sulphate of copper than the line battery.

13. In sending, attention should always be paid to the galvanometer, in order to ascertain whether the current passes

out to the line. A clerk should always be able to estimate the sensitiveness of his galvanometer, and to know whether the current which passes through it is weaker or stronger than usual. If weaker, the fault may be in his sending batteries; there may be a disconnection, or partial disconnection, on the line, or a defective point of contact in his key: if much stronger than usual, the fault will be earth on line; if extremely strong, the cause will be earth near his station, or perhaps in the office.

14. As the relay completes a circuit of feeble resistance, its bearings and contact points are apt to be oxydized, or even burnt, and the bar should always be connected to its bearings by a fine spring, or by a drop of best salad oil, which will convey the current and protect the pivot points.

15. When the local batteries are so joined up that the copper is connected to the bar, the oxydation takes place at the pivot, sometimes completely insulating it and breaking continuity. The copper current should therefore always be made to flow from the bearings to the pivot, not *vice versâ*.

16. The contact points of a Bain relay are not so subject to be fused as those of a Morse; for in the first system the "local" consists of small cells which do not fuse metals, but, on the other hand, they more readily effect oxydation.

17. As the large cells of a Morse local readily burn a fine point, they frequently cause a relay to "stick," by fusing together its points of contact, which must be kept clean and bright by scraping with a knife or very smooth file.

18. The current burns or hardens the oil used on the pivots. If too much oil is used on the key it becomes mixed with metal-dust and dirt, so as to coat over the insulated parts.

19. A key sometimes fails from the earth contact not being fairly broken before the line contact is established.

20. A dirty key will frequently send a current on short circuit, but not on the line. This happens when the resistance of the line, added to that of the key, is too great for the current to overcome.

COOKE AND WHEATSTONE'S NEEDLE TELEGRAPH.

324. The needle instrument is simply a vertical galvanometer (82) with a key or apparatus for placing a battery in circuit, and for reversing the current.

The lower end of the inside needle is a north pole.

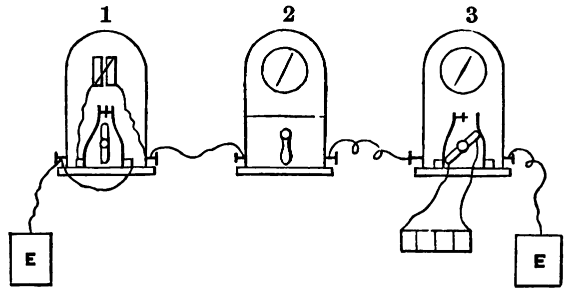
The coils are generally wound so that if the copper of a battery be connected to the left, and the zinc to the right hand terminal, the top of the needle moves to the right.

325. When several instruments are connected in circuit, the wire connected to the right hand of the coil in the first must be joined to the left hand of the coil in the second, and so on, so that the current may flow always in the same direction, for the direction of the movement of the needles depends on the direction of the current (80).

Take three stations, 1, 2 and 3. If the left side of the coil 1 be connected to the earth, and the right to the line wire leading to 2; then, to make the current traverse the coil 2 in the same direction, it must enter at the left, and leave by the right, and the line wire coming in from 2 must be connected to the left side of the coil at 3, which being

the terminal station, must have the right side of its coil connected to the earth.

Thus, the *up* station earth and all the *up* wires are connected to the *left*, the *down* station earth and all the *down* wires to the *right*, and *vice versâ*.



The principle is the same however the connections and works of the instrument may be arranged.

In fixing needle instruments, the practical rules are :—

Connect the instrument so that when on short circuit (*i.e.* when the "in" and "out," or "up" and "down" terminals are connected by a short wire) the needles move in the same direction as the handles.

After connecting up a new instrument on a double-needle circuit, give the test signals + E H N slowly, making a long pause after N, to separate each group of signals, and to show when the group is commenced.

If a single needle, give E T in a similar manner, until some station sees the signals and repeats them.

If they are not repeated correctly, you will be able to change your wires until they appear properly on your own dial.

If you receive E + N H, both your needles are wrongly connected, and the line and earth wires must be reversed.

If + E N H, the + E wires are correct, and the H N reversed, and so on.

Whenever unintelligible signals are received, the test signals should always be given, in order that the distant station may have a chance of communicating by altering its wires; or that you may see what is wrong, and alter your own wires so as to give any necessary instructions.

326. If the line wires of one of the instruments be reversed, the signals *received* at that station will be reversed also; *forwarded* signals will be read correctly on its own dial, but will be reversed at other stations.

If the battery wires be reversed and the line wires correctly connected, signals will be *received* correctly at the station; but those *forwarded* by it will be *reversed*, and the needles on its dial will move in the opposite direction to the handles.

If both line and batteries be connected wrongly, received signals will be reversed, but other stations will be able to read, because the effect of reversing the line is counteracted by the reversal of the batteries. The needle will still move in an opposite direction to the handles. It is evident that no alteration of the battery wires can affect *received* signals.

327. The faults to which the needle instrument is subject are :—

1. Demagnetization by lightning, or from want of what is called retentive power in the needle, causing the signals to become weak or to cease altogether.

2. Reversal, when the poles of the needle are changed by lightning, and the signals appear reversed, as if the batteries were strongly connected. In these cases the needle must be remagnetized, and in effecting this care must be taken not to bend the pivots (77).

3. When the needle can be moved in one direction only, from one pole of the battery at the station having become permanently connected to the earth, from damp in the battery

room, accidental contact of a battery wire or plate with the earth; or a contact between one of the battery connections inside the instrument and the earth or line, caused by metal dust worn from the pins or bearings, dirt and oil, or pieces of coil wire broken off.

In the case of earth on the battery wire or battery, the needle can be moved one way when the faulty wire is disconnected from the instrument. If the needle can be moved when either battery wire is off, both wires make earth.

4. One station is able to speak to all the rest, but no other station can give a signal. This fault will be found at the station which is able to work, and is caused by the circuit being broken by dirt on the points on which the line springs rest.

Moving the handle of the faulty instrument removes the spring from the points on which it rests and completes the circuit through the battery, so that signals can be *sent;* but in order to *receive,* the circuit must be re-established at the points. The dirt prevents this.

A case has occurred in which communication was restored by burning up this dirt by a powerful current sent on the line from another station.

5. Signals are uncertain; they sometimes miss. A battery plate is defective, or a connection is loose, and the jar caused by moving the handle breaks the circuit; the battery pins, or the springs or blocks on which they rub, are dirty or rusty. When one side of the battery pin is dirty and the other clean, the needle can only be moved one way. In a double-needle instrument, if one needle only is faulty, the defect will, of course, not be in the battery, but in the instrument connections.

Bad oil frequently causes this class of fault.

6. Signals can only be made by moving the handle as gently as possible, and, when made, fail if a little extra

pressure is used. The cause is a defective connection, which is broken by the extra pressure.

The fault is readily found by holding the handle in such a manner as to cause the signals to fail, that is, so as to break the circuit, and connecting the points of contact, one by one, by a knife or a bent wire, until a part is found, on touching which the needle moves, showing that the fault has been bridged over (242).

7. The needle sticks to the ivory pins: wipe them carefully, or rub the edge of the needle with a black-lead pencil. The needle is not free to move in the coils, or the pivots are too tight, or bent: examine them and make the necessary adjustments.

8. The needle moves in an opposite direction to that of the handle of the instrument. The batteries may be reversed; the needle reversed by lightning; or the coil wires crossed.

Examine the battery wires and the coils; see if the N. pole of your magnet repels the lower end of the needle as it ought to do.

9. Sometimes one of the spiral springs which secure the connection of the battery with the barrel, is bent, so that when the handle is moved it connects one pole of the battery to the line or earth, and thus puts it on short circuit.

10. Contact between the two needles of a double-needle, generally intermittent. If not on the line, the cause may be this: the inner ends of the coil wires are soldered to the metal of the coil frames, so that when the two half coils are placed in the slide, the coil wire is connected with it and with its dial. Thus, if anything occur *to form a connection between the two dials,* which are ordinarily insulated, the wires of the two coils will be in contact, and the current will divide between them.

This sometimes happens through the metal face of the case of the instrument, if the ivory pegs placed in the dials

are worn away, or if the case is warped so as to press the face upon the dials.

11. At railway stations persons sometimes place books and parcels away under the instruments; occasionally a key or other conductor will be laid so as to touch both the bolts which screw down the "works" of the instrument, causing intermittent contact.

12. Cross or "crooked" handles; causing an occasional disconnection in one of the wires, sometimes a contact.

If the interruption ceases when one particular station works, call that station if possible; if not, call every station you can, and ask each to look at his handles. If a barrel is stiff in its bearings, these faults frequently occur. Too great care cannot be taken to make them work freely, and to prevent wear by careful oiling with *best salad oil,* not lamp oil. (See method of finding cross contact.)

13. Wire broken inside percha, especially when the instrument is not screwed down.

14. Wires connected, when two or more are fixed down by a staple, which cuts through the percha.

15. Coils fused by lightning, or coil wire broken.

In this case the needle will not move on short circuit, or when the line terminals are connected by a wire; even after it has been remagnetized.

If there are no spare coils to replace those which are damaged, the following temporary expedients may be adopted:—

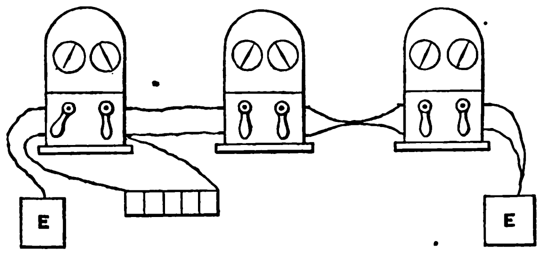
If one-half the coil is defective, remove it, and connect the terminal to which its wire was fixed, to the bar on which the coils slide, leaving the remaining half in circuit.

If both halves are useless, take one-half of the other pair of coils, completing the circuit, as in the former case, by

connecting the terminals left vacant to their respective frames. The signals will be weak, but readable.

If both sets are damaged, connect the coil terminals across, so as to enable the rest of the circuit to be used.

16. Cross contact on double needle.



When the wires of a double needle are in contact, if one of the handles of an instrument be moved, it will make Q, or Z, on the sender's dial, and either Q Z, or R W, on the other dials in circuit.

Suppose the handle be moved as if to make E, the current will pass along the + E wire to the place of contact, and will divide there among all the channels open to it; part will continue along the wire on which it was sent, part will pass into the H N wire, and flow along it to the earth at each end, part travelling back through the sending station to earth, and part through the stations beyond the fault to earth.

The current in the H N wire will travel in the *same direction* as in the + E to the earth beyond the fault, and in a *reverse direction* to the earth on the same side as the sending station (252).

Thus the needles of all stations on the same side of the fault as the sending station will move in *reverse* directions, and those beyond the fault in a parallel direction.

By calling the several stations and getting them to give

+ E H N you may find, with certainty, between which stations the fault lies.

Call the middle one; if you receive Z Q Z Q, the fault is beyond that station.

Call the stations in succession until you find one which gives W R W R. This station is on the opposite side of the fault to those giving Z Q Z Q.

There is but one exception; when every station gives Z Q Z Q for + E H N, the earth is defective at one of the terminal stations.

328. When a line is badly insulated, it is not desirable to use too sensitive an instrument upon the shorter circuits of the line. As a last resource the coils may be opened, that their action on the needle may be so far lessened as to render it insensible to the leakage from the longer circuits, and the battery power may be a little increased to make up for the want of sensitiveness.

It is better to use coils wound with a thicker wire (No. 30), and thus by decreasing the resistance of the circuit, lessen the tendency to leakage.

329. Thicker wire in the coils is useful where the resistance of the instruments is very much greater than that of the line; for instance, when 12 or more are in circuit on a wire under 30 miles in length; but it is better that the terminal instruments should have fine wire coils.

BATTERY FAULTS:—

330. *Weak current.* Sulphate of copper exhausted. Sulphate of zinc solution too strong, perhaps crystallized upon the zincs; it should never be allowed to become more than half saturated.

Zincs covered with deposit of copper.

Terminals corroded, or incrusted with dry sulphates; this fault is very frequent.

A cell partly empty, the liquid drawn off by the siphon-like action of the crystals of sulphate of zinc (55).

Dirty connections, battery making earth from damp; wires badly insulated, making earth or contact.

Intermittent current.

A battery plate broken, touching at times, and at other times becoming separated.

Loose battery wire.

No current.—Broken battery wire or plate; empty cell; battery wires in contact, perhaps where stapled down to the table or wall; or earth.

331. ALARUMS.—The *direct action* alarum consists of an electro-magnet whose armature carries a hammer which strikes a bell when a current is sent on the line. They answer very well for short distances where a sufficiently strong current can be obtained to act on an electro-magnet wound with thick wire.

For long distances, where but a feeble action can be secured (93), the electro-magnet is wound with fine wire, and simply liberates a detent, so as to start a train of wheels moved by a spring.

The armatures of the latter class of alarums are apt to stick, because only a very slight force can be applied by the spring which removes the armature after the current is cut off. This inconvenience can be remedied by the use of a ringing key, which sends a reverse current (306) of very short duration.

Residuary magnetism (81) is a frequent cause of sticking, and can be prevented by occasionally reversing the connections of the electro-magnet.

PART IX.

THE CONSTRUCTION OF A LINE OF TELEGRAPH.

332. In order to establish communication between two places it is necessary to erect a wire of sufficient conductibility, and to insulate it sufficiently well. A good earth connection must be provided at the terminal stations, and a circuit formed, including the earth, the apparatus, the line wire, the apparatus at the distant station, and the earth again. Intermediate stations are introduced by cutting the wire, and placing the instrument between the divided ends.

333. Leaving first cost out of consideration, it is far better to use suspended rather than buried wires, because of the liability of gutta-percha and india-rubber to deteriorate, and the expense of repairing faults. It is better to use iron wires carried on poles over tunnels than covered wire through them, and, as a rule, both percha and rubber should be avoided as much as possible.

334. Foreign timber is the most durable, but its price precludes its use, except where a more sightly appearance or extra strength is required. English larch, from 30 to 40 years'

growth, cut close to the ground so as to obtain the "natural butt" of the tree, having its rings close, and containing a fair proportion of heart wood, if felled in the winter and well seasoned, is both cheap and durable. If possible the poles should be prepared with some antiseptic, such as creosote, or sulphate of copper. The poles, if unprepared, should be barked and stacked in such a manner as to allow a free circulation of air among them, the lowest tier being raised several inches from the ground. They should be protected from the sun, so as not to dry too quickly, or they will split. If the bark is allowed to remain on the splitting will be prevented, but they are liable to be attacked by boring worms and other insects, and it is not certain that the sap, when prevented from drying out quickly, does not ferment, so as to form the germs of decay.

The butt ends should be well roasted over a slow fire. A foot below and a foot above the intended ground line should be slightly charred, and tarred, when hot, with a mixture of four parts of gas tar (boiled with powdered *quick* lime, to expel the water and ammonia,) and one of Stockholm tar. When set on the line they should be allowed to remain for three or four months to dry thoroughly before they are painted, and should not be painted except in dry weather.

If it should be impossible to procure seasoned timber, the butts should be charred and baked, *but not tarred*; for coating green timber prevents its drying, and causes it to decay. When the timber has become well seasoned, the soil may be removed to a depth of at least a foot around the bottoms of the poles; and when this part has become dry, the tarring and painting may be proceeded with.

For lines of ten wires, or less, a diameter of five inches is sufficient. The greater the distance at which the poles are set from one another the stronger must be the timber.

335. In all cases where it is possible the wires must be placed within sight from the trains, so that they may be readily inspected. Bearing this in mind, the poles should be set at the greatest possible distance from the metals.

336. The smaller the number of poles to the mile the better will be the insulation and the less the cost, but the greater the liability to accident.

Experience has shewn that for a telegraph of more than four wires, there should not be less than 20 poles to the mile on straight parts of the line, and a greater number on curves, dependent on the radius (or sharpness) of the curve, and on the direction of the strain; when the poles are set on the outside of the curve, the strain tends to pull them towards the rails; and if a wire break loose, it will hang nearer the trains than it did when in its place; so that there is a greater chance of accident than when the poles are on the *inside* of the curve, and would fall from the metals. On branch lines where not more than four wires will be required, 16 poles per mile, or even fewer, are sufficient, provided they can be set so far back that if they fall they may clear the rails.

337. The pressure of the wind on the poles and wires is very great in a gale, it is therefore desirable to erect the telegraph on the *lee side* of the railway, where it may be sheltered from the prevailing winds. Where the line runs north and south, the east side should always be chosen. In cuttings, where the wires are sheltered, although the poles are necessarily set near the rails, the risk is much less than on embankments, where the wires are fully exposed, and where a side wind will blow them several inches, or if the spans are long a considerable distance, across the line.

Care must be taken that the wires are perfectly clear of swinging cranes and railway signals, as intermittent earth

is frequently caused by the wires being blown against them by the wind.

338. The poles must always be made to lean back against the strain of the curves, and should be stayed so as to oppose the strain. On straight lines, especially when exposed to the wind, double stays, to prevent their moving either way, are required; for if one stay only is used, the poles will spring back during the lulls of a gale blowing from the side opposite to the stays, and the wires will not only be made to swing, but the stay will be loosened, or even broken. Each pole must be made as stiff as possible, in order to be perfectly secure. The earth must be well rammed, especially at the top and bottom of the hole; and if stones can be obtained they may be so placed as to give the pole a firm thrust against the undisturbed part of the soil.

339. However well rammed, stays are apt to draw and become loose in light soil. When large stones cannot be found an iron stay anchor, or a piece of an old pole sound and well charred, can be used. And in all cases, most especially in sand, the hole should be *undercut*, so that the stone or log may have a pull against the solid undisturbed earth.

Wire stays are apt to rust at the surface of the ground, and should therefore be well tarred or painted; an iron rod projecting a few inches above the soil, to which a wire can be fastened, is to be preferred. And for terminal poles, or poles having great strain, rods, not twisted wire, should always be used. It is very difficult to make a stay of several wires, whether twisted or not, in such a manner as to distribute the strain equally between all the wires of which it is composed.

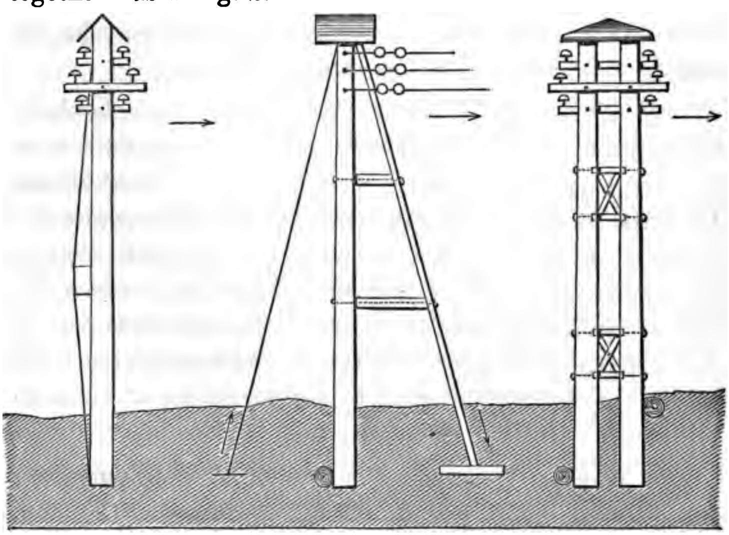
340. When a stay is fixed to the top of a pole on which there is much strain, the pole bends below the stay; if the stay is fixed below the wires, the pole bends above. In such

cases the stay should consist of two branches, one fixed above, and the other below the wires, uniting into one a few feet below the lowest wire.

Poles exposed to great strain may with advantage be "trussed" like a girder (fig. 1).

In soft soil struts are to be preferred to stays, as they compress instead of lifting the earth; but whenever a strut is used it must be remembered that the strain of the wires tends to bend the pole below the strut, the point of the latter acting as a "purchase," or fulcrum; and, again, that the strut itself is liable to bend.

These inconveniences are met by tying the two together with bolts, to prevent their being forced apart, and placing pieces of timber between them, to oppose their being pressed together—as in fig. 2.



1 2 3

Fig. 1.—The strain acting in the direction of the arrow tends to render the opposite side of the pole convex; but the pole cannot bend without stretching the truss wire, which

should always be fixed round the bottom of the pole; for if fixed at the ground line it will give it a tendency to break off at that point.

The strain of the wires on the terminal post (fig. 2) tends to push the strut out into the ground. A stone or piece of timber should therefore be placed under the foot of the strut, to give it an enlarged bearing.

The strain will also tend to turn the pole upon the fulcrum formed by the upper extremity of the strut, so as to lift the heel of the pole out of the ground. A sleeper or log, well backed up with large stones, should therefore be so placed as to give the pole a solid thrust against the firm soil (fig 2).

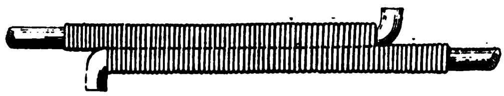
341. Where neither stays nor struts can be fixed, use a double-framed pole with a sleeper at the bottom and top of the hole (fig. 3), to give a broad bearing; or two poles set side by side and bolted or strapped together.

342. When poles are set over tunnels or bridges, in places which are not within sight, or where there would be more than ordinary difficulty in executing repairs, the work should be unusually strong, the best wire used, and greater distance given between wire and wire, so as to make such portions less liable to interruption. In such places it is also desirable to use iron-hooded insulators, and to fix guards to protect the insulators from damage by stones, and to catch the wires should they become detached by the insulators or bindings breaking.

343. Wires.—No. 8 gauge is used for ordinary purposes; No. 11, which gives just double the resistance of No. 8, is sufficient for short unimportant circuits; and No. 4, of half the resistance of No. 8, may be used with very great advantage for long important lines. The smaller the wire the more perfect must be the insulation, because an increased

resistance in the wire virtually adds to the length of the circuit.

344. It is of the greatest importance that every joint should be perfectly *soldered*, for a twisted connection always fails, sooner or later, and is apt to break from the hardening of the wire in twisting. The so-called "Britannia" joint is the strongest and best.



It is made by slightly bending up the ends of the two wires, laying them side by side, binding them tightly together with No. 16 wire, and well soldering the whole. The bent ends should be cut off close, to prevent the formation of wind contacts; for when wires are blown together they are apt to be hooked permanently by such projections.

345. As metals expand and contract with the variations of temperature, wires put up in the summer must be strained less tightly than if fixed in winter, or their contraction will break them.

Iron expands $\frac{1}{14616}$ of its length, or about $4\frac{3}{10}$ inches per mile for every ten degrees of heat; so that between winter and summer, or 32° and 62°, there will be on a line of 20 poles to the mile, a difference of length in each span of wire of nearly seven-tenths of an inch.

Although the strength of a wire increases in proportion to its size, yet a thick wire will be as liable as a thin one to be broken by frost; for a thick wire will, obviously, exert more force in contracting than a thin one, and will be more likely to tear down its supports if strained too tight. Wire should be well annealed, so as to bear bending, and should stretch before it breaks. For very long spans a stranded wire is used, being less liable to break.

346. Wires break at the defective welds and the weak places, and it is most desirable to find out and remove these causes of accident beforehand. The wire should therefore be strained till it stretches, after it is laid out on the line, so as to break it if defective. This process will also remove the wrinkles and irregularities, so as not only to make the wire look much better, but render it less liable to be set swinging by the wind, and, should it be put in motion, less liable to catch and remain in contact. If a straining machine is not at hand, let it be drawn as tight as possible by ropes and blocks, and then pulled at the centre of its length across the line till it stretches. It will be found to have lost its spring, so that it can be very easily handled.

347. When a wire passes free through an insulator, it is apt to chafe and wear, especially in long spans. It should therefore be bound securely to its supports, even though the leakage is increased by the enlargement of the surface of metal.

348. The distance between wire and wire should increase with the span. Ten inches vertical distance and 13 horizontal has been found scarcely sufficient where there are 24 poles to the mile; but where only 20 poles are used, 12 inches vertical and 16 inches horizontal is the minimum. When the insulators are fixed each on a separate support, they should be placed alternate, not opposite one another; and if two are fixed on an arm, the arms may with advantage be of two lengths—say 20 and 28 inches alternately—so that if a wire drop it may hang clear of the one below it. The lowest wire must be out of reach from the ground.

349. Thick wires should never be used in crossing a line of railway, except, perhaps, at stations. If a stay give way, or anything occur to lower a wire, it will be caught by the train, and being too strong to be readily broken will allow the

engine to drag down a considerable length of the telegraph. If No. 12 or 14 wire be used, the engine will snap it, and no great harm will ensue.

350. In deciding on the strength of a line it must not be forgotten that on very rare occasions, when the air near the ground is rather colder than above, and when snow falls at a temperature a little above freezing, it adheres to the wires, and if the downfall continue will coat them to a sufficient thickness to break them and the poles. In Holland the mists freeze upon the wires, giving them a coating of several inches diameter, which splits when the sun breaks out, forming, as it were, splinters which interlace and connect the whole of the wires.

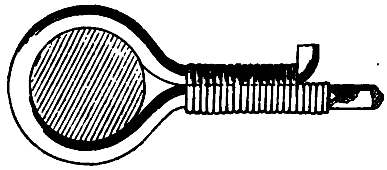
351. The zinc coating is no protection to the iron if it be exposed to smoke. In the neighbourhood of chimneys, and in or near towns, the wires must be painted or varnished with tar when erected.

352. The noise caused by the wind may be effectually prevented by securely binding strips of wood about 18 inches $\times 1'' \times \frac{1}{2}''$ on each side of the wire near the poles, so as to check the vibration.

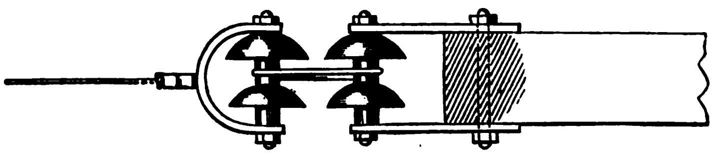
353. Each pole should be furnished with an earth wire or lightning conductor (149), which should be put on the pole before it is fixed, and be formed into a flat coil attached to the foot of the pole, so as to expose as large a surface as possible to the earth. It must be securely *soldered* to the brackets which hold the insulators, or the bolts by which the arms are fixed on, and must not be tarred or painted.

It is very important this wire should make good earth.

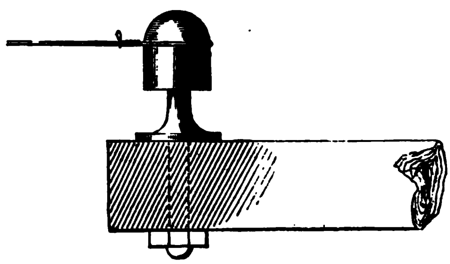
354. In "terminating" a wire it should never be twisted, or it will break. It must be wrapped once round the insulator and bound as shown in the figure.



355. The insulators should be so fixed that they will take a direct strain, hence shackles are to be preferred to insulators fixed upon a pin.



As the iron pin passes through the insulator of the shackle, should the earthenware break the wire will not fall; but, on the other hand, as the current can escape upwards as well as downwards, it requires two insulators, or a double shackle, as in the figure, to give the same resistance to leakage as that of an *invert* of the same model and size (142).



Insulators should always be securely fastened to the arms or brackets, for when the pins simply drop into holes they are frequently lifted out by wind, causing a stoppage.

356. Leading Wires into Stations. As percha wire is

very perishable when exposed to air and light, it is imperative to leave as little as possible uncovered, and to enclose it in an iron pipe or a well made wood casing, carefully fitted and painted.

The percha should be covered with tape and varnished with Stockholm tar in outdoor work, and well painted indoors. The length left exposed must have a double coating of tape and tar.

As the dirt on the exterior of percha conducts when damp, a short length of the loop which extends from the casing to the linewire should be protected from rain by a porcelain or stoneware bell or large tube, so that a portion of dry surface may break the line of leakage.

However well percha may be covered with tar it needs retarring every autumn, or twice a year, and if this be done it becomes almost everlasting.

357. IN FIXING EARTH PLATES care must be taken that the principles laid down in sections 132, 133 be complied with, so that a perfect earth may be obtained.

358. SOLDERING.—There is nothing more important than the perfect continuity of a circuit, and this can only be attained when every connection or joint is well *soldered*.

No joint, however clean and firm, can be depended on if made by mere contact, for the metals will rust or oxydize sooner or later, and the passage of the current will increase this tendency.

Connections in apparatus must never be soldered with acids, or chloride of zinc. These liquids cannot be entirely removed, and will corrode the metals. If spilled on the wood chloride of zinc never dries, and spoils the insulation. Rosin must always be used.

For soldering wires exposed to the weather, a greater choice of materials exists, for the joints are washed clean by

the first shower. Yet there is danger in using muriatic acid, as much mischief may be effected before the rain comes.

Chloride of zinc (or "spirits of salts killed by zinc") is much better; after soldering rub the joint with a lump of rosin while hot.

Salammoniac is very useful for tinning iron, and may be conveniently applied in powder.

When copper and iron wires are connected it is better to wash off the chloride of zinc, and to smear the joint with paint or rosin, especially in a smoky place, to prevent local action between the metals.

359. Jointing India Rubber and Percha.—The weakest portion of every piece of "covered work" is the joints.

The following are the instructions given by the Gutta Percha Company;—

"Have in readiness a few strips, about $\frac{3}{8}$ inch broad, of very "thin gutta percha sheet, also a little *warm* gutta percha, "about $\frac{1}{8}$ inch thick, one or two hot tools, and a spirit lamp.

"Remove the gutta percha covering from along the wire "no further than may be necessary for making the joint in the "wire. Having joined the wire, warm gently with the spirit "lamp the bare wire and joint, and the gutta percha near to "it. Taper the gutta percha over the bare wire until the ends "meet; warm this and immediately apply one of the strips of "thin sheet in a spiral direction over it. Press this covering "well on until cool, then, with the spirit lamp, carefully warm "the *surface* and proceed as before to put on a second strip of "the thin sheet, observing to wrap it in a direction reverse "from the first strip, always making the commencement and "termination of these coverings to overwrap the previous one. "*It is safer to perform this operation a third time.* Next, take "a piece of the warm $\frac{1}{8}$ inch sheet and cover over the coats of "thin sheet, again overwrapping the original covering of gutta

"percha, which should be heated so as to ensure perfect adhe-"sion. Press it well on as it cools, and when cold, or nearly "so, finish off the joint with a warm tool, working well "together the old and new material at each end. Lastly, and "in general, avoid moisture, grease, or dirt, and be careful "not to burn the gutta percha, which would prevent proper "adhesion.

"It is well to clean and soften the surface of the percha "with rectified coal naptha.

"Cleanliness is most essential to success. The fingers should "be used as little as possible, and must be kept very clean. "The kneading and finishing the joint should be performed by "the tools provided for that purpose.

"Moisture, tar, dirt and grease, are fatal to a joint. The "thin strips must be kept clean and dry in a small box."

360. Rubber joints are made in the same way as percha, except that heat is not used, and that the strips are well moistened with rectified coal naptha. It is well to cover percha joints with a layer of rubber.

No one but the lineman in charge of the work, who will have the trouble of repairing it if defective, should be entrusted with the delicate operation of making joints.

PART X.

THE STRAIN AND DIP OF SUSPENDED WIRES.

361. The weight of a suspended wire causes it to hang in a curve, or to dip. The more it is tightened the less it dips, so that its *tension* is proportional to its dip. The *weight* depends on its size and length.

362. If it be required to increase the distance between the supports, or to increase the *span,* and yet to preserve the same *tension* in the wire and the same strain at the supports, the dip must be increased as the square of the number of times the distance or span is increased. Thus, if for a span of 100 yards the dip be 1 foot; for double the distance, 200 yards, the dip will be $2 \times 2 = 4$ feet; for three times the distance, $3 \times 3 = 9$ feet, and so on.

The mathematical formula is :—

$$S^2 : s^2 :: D : d.$$

Where S is the original span, s the proposed span, D the original dip, and d the dip required by the increased span to preserve the same strain and tension—

$$\text{Thus } 100^2 : 200^2 :: 1 : 4$$
$$\text{and } 100^2 : 300^2 :: 1 : 9$$

From this formula, which is sufficiently correct for all practical purposes, may be ascertained, not only the dip of any proposed span, but the span of any proposed dip.

Thus, suppose we have 30-feet poles, and wish to learn the greatest distance at which they can be placed apart so as to keep the wires ten feet from the ground and to preserve the strain equal to that given by a dip of one foot in 100 yards, we have—

$$100^2 : s^2 :: 1 : 20.$$

because we can give a dip of 20 feet instead of 1 foot. Multiplying together the two extreme terms of our proportion and the two means—

$$100^2 \times 20 = s^2 \times 1$$
$$\text{and } s = \sqrt{200.000} = 447 \text{ yards nearly.}$$

363. The *span* being the same, the *dip* will vary inversely as the tension and *strain*. If with a strain of 200 lbs. it dips 30 inches, with a strain of 300 lbs. it will dip 20 inches, and with 400 lbs. 15 inches.

364. The *strain at the supports* will, of course, depend, not solely on the tension of the wire, but on its weight and tension combined.

365. The tension is not the same at all points of the curve. It decreases from the supports downwards, and is least at the lowest point; but in lengths under 150 yards the difference is small.

366. When both supports are the same height, the lowest part of the curve is in the centre of the span; when one is higher

than the other, the lowest part is nearer the lower support, so that the greater part of the weight of the wire is borne by the higher pole. In calculating the strain, the wire should be considered as if prolonged beyond the lower end to a point equal in height to the upper one, and the dip should be proportioned to the length thus increased, or to twice the distance from the top to the bottom of the dip. It is desirable, therefore, that the two ends of a long span should be fixed as nearly as possible at equal heights.

367. When the tension at the lowest point of the curve is known, that at any other point may be ascertained by adding the weight of a piece of the same wire, whose length is equal to the difference in level of the two points. Thus, the greater the tension, and the smaller the dip, the less will be the difference of tension at different points.

If the wire were pulled up perfectly straight the tension would be equal in all parts.

368. As the tension is least at the lowest point of the curve, a wire is more likely to break at, or near its supports, than in the centre of the span; and the centre of a very long span may with advantage be made of lighter wire than the ends; for then the ends will not have so much weight to support, while the centre will be strong enough to resist the tension at the lowest point.

369. The weight of a wire increases with its strength (the quality being the same); the only advantage, then, in using thin wire for large spans is that the supports have less weight to carry.

370. The greater the dip the greater the *weight* of wire to be supported, so that there is a point beyond which the dip cannot be increased with advantage, because the *weight* will increase more rapidly than the *strain* will diminish.

For a distance of 1,000 yards, with a wire of No. 8 gauge,

the supports being on the same level, the strain will be nearly as follows, as given by Blavier :—

Dip.	Proportional tension at lowest part.		Proportional strain at supports.
186 yards	70	...	88
218 „	60	...	81
271 „	50	...	77
353 „	40	...	75
516 „	30	...	81

So that, with a span of 1,000 yards, and a dip of 353 yards, the strain at the supports will be the least possible, while with a dip of 516 yards, it will be as great as with a dip of only 218 yards.

380. But in practice the dip cannot be made as large as those in the table, so that the practical rule is :—make the supports as nearly equal in height as possible, and the dip as large as you can.

381. Blavier states, "When the distance which separates "the points of suspension is very small, the contraction of the "wire diminishes the dip in a greater proportion than when "the distance is considerable, and consequently the increase of "the tension is more sensible." (Cours de Télégraphie, p. 261.)

382. A wire should never remain tightened up to more than one-fourth of its breaking strain, which varies with every sample of wire. It should be pulled up first to one-half of the breaking strain to test it, and afterwards slacked out. Where the breaking of the wire would be inconvenient, it may be tested before it is put up (346).

APPENDIX AND NOTES.

383. *Method of Vibrations:*—

If very great accuracy is required in measuring the relative strength of currents, the method of vibrations may be used.

Place a horizontal galvanometer east and west, so that the needle is at right angles with the coils; the current will now have no effect upon the needle while at rest.

Connect the galvanometer in circuit in the usual manner, and cause the needle to vibrate.

The strength of the current will be inversely as the square of the number of seconds occupied by the needle in performing any fixed number of vibrations.

Say that with a certain current A the needle makes 20 vibrations in 10 seconds, and with another current B 20 vibrations in half the time, or 5 seconds. Then, as 5×5 is to 10×10, so is the second current B to the first current A, so that B will have $\frac{1}{4}$th the force of A. The stronger the current the faster the needle will vibrate.

384. *To construct a correct scale for an ordinary detector or a horizontal galvanometer* (84) :—

1. Find the resistance of the coils (221) and of the battery employed (388), and by means of the rheostat adjust the resistance of the circuit till the needle marks 10° on the scale.

2. Halve the *total* resistance of the circuit, the force acting on the needle will now be doubled. Mark the deflection as 20 .

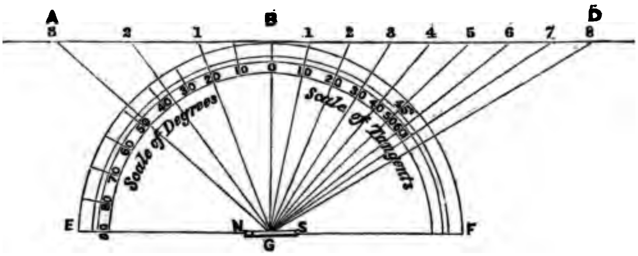
3. Again halve the resistance, the deflection will once more be doubled, and may be marked 40°, and so on.

Suppose the battery resistance be	... ...	1 unit
That of the detector	... ...	10 „
And the resistance added to reduce 10°	...	109 „
The total resistance will be	...	120

To double the force acting on the needle, one-half 120, = 60 units, must be removed from the circuit.

When the detector and rheostat have a very great resistance compared with that of the battery (as for instance when one large cell is used), the battery resistance may be disregarded.

385. *To construct a scale or dial for a tangent galvanometer :—*



A *tangent* is a line drawn at right angles to one of the radii of a circle and touching its circumference. A B and B D are tangents to the circle in the figure.

When a short needle N S, with a pointer attached to it at right angles, is suspended in the centre of a circular coil of wire fixed perpendicularly to the dial E B F, and the apparatus

is so placed that the coil shall exactly face east and west, if the needle is deflected by a given current to 20 degrees, double the force will not deflect it a *second* 20 *degrees*, but to *double the distance measured on the tangent* A B. If the marker be long enough to reach A B, and that line be divided into any number of equal parts, these divisions will indicate equal forces, and will serve as a scale.

Thus, the equal divisions 1, 2, 3, on the line A B represent equal forces; and as G 1 is the position of the pointer when the needle is deflected 20°, doubling the force will deflect it to G 2; trebling the force to G 3, not to twice or thrice 20°, as may be seen by the figure.

It would be inconvenient to read off from the straight line, and the circle may be divided with sufficient accuracy for most purposes by drawing lines from the centre to each division on the line of tangents, marking where they cut the circle. The greater the number of equal parts into which the straight line is divided, the more accurate will the divisions of the circle be, for these last divisions are not all the same length, but decrease as the angle of deflection increases.

In trigonometrical tables the tangent of 45° is 100, so that if this tangent of 45 be divided into 100 equal parts, and these set off on the circle, the readings will correspond with those which would be obtained were the circle divided into *degrees*, and the table referred to for the corresponding tangents.

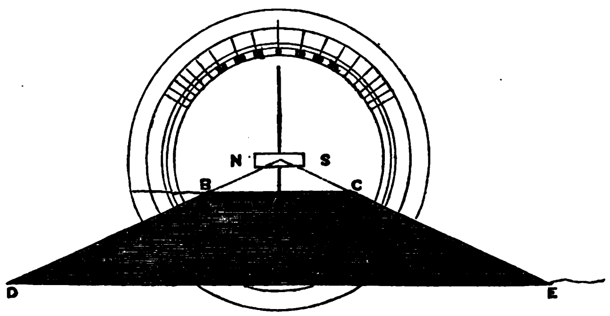
386. *Gaugain's "Tangent Multiplier:"*

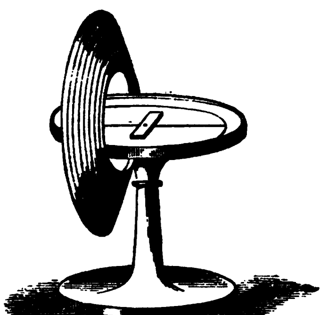
"If a magnetized needle is submitted to the action of a "circular current placed in the magnetic meridian; when the "centre of the needle occupies the summit of a cone having "for its base the circular current, the tangents of the angles "of the deviation of the needle will be nearly proportional

"to the force of the current, when the height of the cone is "equal to one-fourth of the diameter of its base."

This theorem is correct within $\frac{1}{1300}$ when the needle is from 1·17 in. to 1·36 in. in length, and the coil (or circular current) not less in diameter than thrice the length of the needle.

The wire of the coil may be wrapped upon the surface of a cone, or section of a cone fulfilling these conditions; till sufficient breadth is obtained to give the necessary sensitiveness. Nor is the accuracy of the instrument lessened by wrapping several layers of wire one over the other.



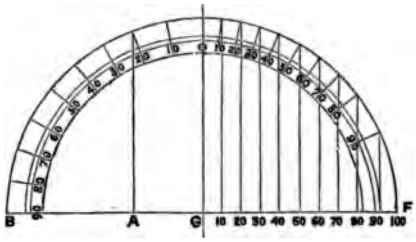


Let N S, the needle, be 1 in. long.

The nearest wire, B C, of the circular coil must be placed

¾ in. from the centre of the needle N S, and its diameter, B C, must be 3 ins.

The angle of the conical coil frame D B A C E is found by drawing straight lines from the centre of the needle through the points B and C. The breadth of the coil may be as great as may be thought necessary. (See Gavarret: Traité d'Électricité, Vol. 2, pp. 54, 55, 56.)



387. *To construct a scale or dial for a sine galvanometer* (88).

The sine of any number of degrees is that part of the diameter of a circle included between a line drawn from its centre to the zero point of the graduation G O, and another line parallel to the first, cutting the circle at the degree whose sine is required; thus A G is the sine of 20°.

When the coils of a galvanometer are made to follow the needle until the force of the current and the directive power of the needle balance each other, so that the needle points to zero, the force of the current acting on the needle will be proportional to the sine of the angle (or number of degrees) through which the coils have been moved.

The sine of 90° is equal to radius, and is 100 in the tables of sines. Divide the radius G F into 100 equal parts, from which draw lines at right angles to G O, and mark the points at which they cut the circle. The readings of the scale so formed will correspond with those which would be obtained

if the deflection of the needle were read off in degrees, and reference made to the printed tables for the corresponding tangents.

388. *To measure the resistance of a battery* (109).

The *diminution* of the force of a current (loss of deflection) caused by the addition of resistance to the circuit, bears the same proportion to the deflection obtained on short circuit as the resistance added bears to the *total* resistance of the new circuit after the addition of the extra resistance. (De la Rive: Treatise on Electricity, vol. 2, p. 78.)

Let D be the deflection obtained on short circuit:

R the resistance of the short circuit, including the battery and galvanometer, with the connecting wires:

r—the extra resistance added;

d—the deflection after the resistance has been added:

Then $D - d$ will be the *diminution* of deflection caused by the addition of the extra resistance r, and $R + r$ the total new resistance: and

$$D - d \; : \; D \; :: \; r \; : \; R + r$$

$$D\,r = (D - d) \times (R + r)$$

$$R = \frac{r\,d}{D - d}.$$

Or simply thus:—

1. Connect the battery on short circuit with a galvanometer whose resistance is known, and note the deflection.

2. Lengthen the circuit by resistance coils.

3. Note the deflection now obtained.

4. Multiply this last deflection by the resistance added in the second operation.

5. Find the difference between the first and the second deflection, and by it divide the product obtained in the fourth operation. The quotient, less the resistance of the galvanometer, will be the resistance of the battery.

For example :—

1. Let the resistance of the galvanometer and connecting wires be 5 units, and the deflection obtained 60°.

2. Add 5 units to the circuit.

3. The deflection is now, say 40°.

4. Multiply 40 by $5 = 200$.

5. Subtract 40° from $60° = 20$.

Divide 200 by $20 = 10$; from which deduct 5, the resistance of the galvanometer, which will leave 5 units the resistance of the battery.

It is better to add three or four different resistances (2), and calculate each result separately, taking the mean or average of the whole, thus :—

A Daniell battery without a porous cell gave on short circuit 46°.

When one unit resistance was added, the deflection was 27°.

Then $\frac{1 \times 27}{46 - 27} = 1{\cdot}42$.

With 2 units' resistance the deflection was 19.

Then $\frac{2 \times 19}{46 - 19} = 1{\cdot}40$.

With 4 units 12°.

Then $\frac{4 \times 12}{46 - 12} = 1{\cdot}41$.

Take the mean

$$\begin{array}{r} 1{\cdot}42 \\ 1{\cdot}40 \\ 1{\cdot}41 \\ \hline 3)4{\cdot}23 \\ \hline 1{\cdot}41 \end{array}$$

1·41 will be the resistance of the battery and the galvanometer together.

If the resistance of the galvanometer were one unit, then the resistance of the battery would be 0·41 unit.

To measure E, the electro-motive force of a battery (21).

389. 1. Wheatstone's method:—

Connect the battery with a galvanometer, and introduce resistance until a deflection, say of 30°, is obtained. Introduce more resistance until the deflection is reduced to 25°, noting the length of wire required to produce the *diminution of* 5°.

The greater the electro-motive force, the greater will be the resistance required to effect the diminution of 5°, and the comparative forces of batteries may be expressed by the number of units of resistance employed. (De la Rive: Treatise on Electricity, vol. 2, p. 788.)

2. An approximate measurement, sufficiently close for all practical purposes, may be obtained by placing a few cells, twelve or less, in circuit with a tangent or sine galvanometer, introducing so much resistance, 100 units or more, that the resistance of the batteries to be compared may be neglected. The deflections obtained will then express the relative forces.

This method, however, is inferior to the former, as it does not admit of the reduction of the measurements to a fixed standard, or of the accurate comparison of measurements taken at different times.

390. *Determination of the joint resistance of two circuits between which the current divides, as in the case of a fault, a shunt, or two circuits worked by the same batteries.* (160, p. 66.)

When a current splits between two or more conductors, it divides in the proportion of their relative resistances. If the two conductors are precisely alike, it divides equally; if they are similar, save in length, then the proportion of the current which traverses them is the inverse ratio of their lengths.

Let R and r be the resistances of the two circuits, C and c their conductibility; the two united will have a conducti-

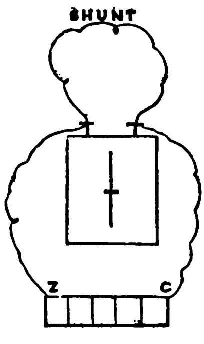
bility x equal to C + c, that is, equal to $\frac{1}{R} + \frac{1}{r}$ (resistance being the inverse of conductibility)—

$$\text{Then } x = \frac{1}{R} + \frac{1}{r}.$$

$$x\,R\,r = R + r.$$

$x = \frac{R+r}{R\,r}$, and the resistance (being the inverse of conductibility) is $\frac{R\,r}{R+r}.$ That is, the resistance of the two circuits, when connected, is equal to the product of their separate resistances, divided by their sum. (Gavarret: Traité d'Électricité, vol. 2, p. 43.)

391. *To arrange a "shunt" on Wheatstone's principle, for reducing the sensibility of the galvanometer, by leading away part of the current through another circuit* (219).



If a current be split between the wire of the galvanometer and a wire attached to its two terminals, called a "shunt," it is evident that it will divide itself between them in the inverse proportion of their resistances (390). If the shunt be exactly equal in resistance to the galvanometer, the current will divide equally, and the deflection will be exactly one-half of what it was without the addition of the shunt.

If the "shunt" be one-half the resistance of the galvanometer, two parts will flow through the former and one through

the latter; the deflection will then be one-third, and must be multiplied by three, to compare it with the deflection given by a wire tested without the "shunt," and so on.

This is perfectly correct where the resistance of the wire is considerably greater than that of the galvanometer and battery, but it is not so for short lengths. For when the shunt is used, the resistance of the circuit being lessened, the battery acts more powerfully, more current passes out to line, and the deflection is proportionally increased.

It is therefore necessary to add to the line, that is, to introduce between the line and the galvanometer, a resistance which will compensate for the reduction of resistance caused by the addition of the shunt, thus making the resistance of the testing apparatus, including galvanometer, shunt, and compensating wire, the same as that of the galvanometer when no shunt was used. (De la Rive: Treatise on Electricity, vol. 2, note B.)

Calculate the resistance of the galvanometer *with* the shunt by the usual formula, and subtract it from the resistance of the galvanometer itself *without* the shunt: the difference will be the length of the wire required to compensate the circuit.

Thus, to halve the deflection of a galvanometer of 10 units resistance, the shunt must be 10 units, and $\frac{10 \times 10}{10+10} = \frac{100}{20} = 5$ units will be the resistance of the galvanometer with the shunt attached.

Subtract 5 from 10, 5 units will be the length of the compensating wire to be added to make the *total resistance of the whole circuit* the same as when the shunt was not used.

Again: if the shunt equalled 5 units—$\frac{10 \times 5}{10+5} = 3{\cdot}33$ units, so that 6·67 units would be required to bring up the resistance to 10 units, as at first.

TABLE.

Amount to which the deflection is to be reduced.	Resistance of shunt required.	Resistance of compensating wire.
To $\frac{1}{2}$	Equal to galvanometer	Half of galvanometer
„ $\frac{1}{4}$	$\frac{1}{3}$ of do.	$\frac{3}{4}$ of do.
„ $\frac{1}{8}$	$\frac{1}{7}$ of do.	$\frac{7}{8}$ of do.
„ $\frac{1}{10}$	$\frac{1}{9}$ of do.	$\frac{9}{10}$ of do.

392. FORMULA *for the effective current or strength of signals on a circuit having contact or partial earth* (161) :—

Let E be the electro-motive force of the battery :

Let R be the resistance of the line from the sending station to the fault, including battery and sending apparatus :

Let r be the resistance of the line beyond the fault, including the receiving apparatus :

Let f be the resistance of the fault :

Then $\frac{E\,f}{R(r+f)+r\,f}$ or $\frac{E\,f}{R\,r+R\,f+r\,f}$ will equal the received current.

The algebraic expression at page 70 is inverted in error.

The manner in which this and the following formula are obtained is given in full by Gavarret. (Traité d'Électricité, vol. 2, p. 88.)

FORMULA *for the effective current on a wire having two faults, partial earth, or contact:—*

Let E be the electro-motive force of the battery :

R the resistance of the wire from the battery to the first fault :

r′ the line wire between the faults :

r'' the wire from the second fault to the distant station, including the apparatus :

L the total circuit $(R+r'+r'')$:

f' the first fault :

f'' the second fault :

$$\text{The current} = \frac{E\,(f'\,f'')}{R\,f''(R+r'')+r''f'(R+r')+R\,r'\,r''+L\,f'\,f''}$$

Or in the case given in section 166, p. 74, E being 1000,

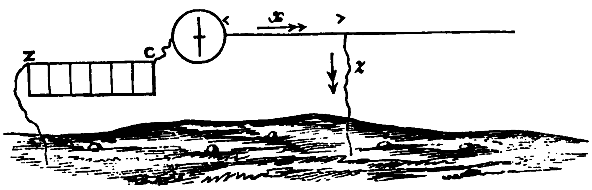
$$\frac{1000\times20\times20}{50\times20\ \ (20+30)+30\times20\ \ (50+20)+50\times20\times30+100\times20\times20}=2{\cdot}4.$$

393. FORMULA *for the resistance of the faulty wire in testing by the loop method* (285) :—

Let the resistance of the longer portion of the loop be ...	x
That of the shorter portion	y
The total resistance of the loop	L
The resistance added to the shorter portion to make it equal the longer	R

Then $x+y=L.\quad x=L-y=R+y.\quad y=\dfrac{L-R}{2}$

394. *Testing for the distance of an earth by the laws of derived currents* (286) :—

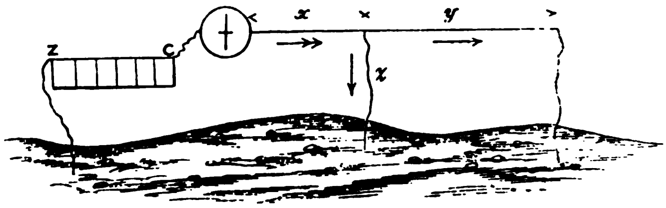


When the wire is *disconnected* at the distant end the current which leaves the battery will go to earth at the fault, and the resistance (R) of the circuit will be :—

That of the wire (x) between the galvanometer and the fault :

And that of the fault itself (z);

Therefore $R = x + z$.



When the wire is *to earth* at the distant end, the current will "split" at the fault, and will divide itself between the fault and the wire beyond the fault. The resistance (r) of the circuit will be that of the wire (x) between the galvanometer and the fault, and the joint resistance of the fault (z) and the wire (y) beyond the fault, or $r = x + \frac{y\,z}{y + z}$ (390).

And when the wire is in good order its resistance (L) is, of course, that of its two parts, x and y.

$$\text{Then } R = x + z$$

$$L = x + y$$

$$r = x + \frac{y\,z}{y + z}$$

$$x = r - \sqrt{(R - r).(L - r)}$$

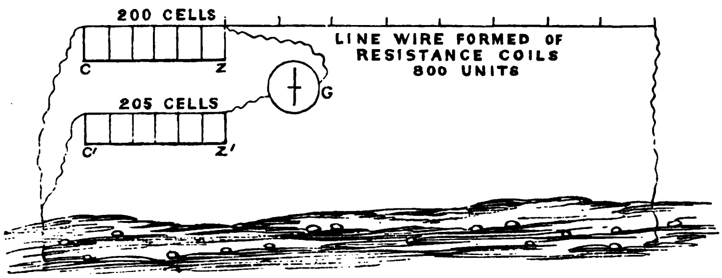
395. *The working intensity of a battery.*

Mr. Varley has shown (page 79) that the effective tension of a battery is lessened by leakages on the line, so that a larger number of cells is required in wet weather than in dry, to give the current the same power of overcoming resistance (intensity).

The following experiment of Mr. Latimer Clark illustrates the same point. ("Submarine" Report, p. 295.)

With a battery, say of 100 cells, the full tension of 100 elements can only be rigorously obtained when the poles are

disconnected, and is very sensibly diminished by the battery being connected to a line wire even 1,000 miles in length. As the resistance of the line wire decreases the tension falls, until a point is reached at which the 100 cells do not cause more current to flow through the wire than would be given by a single large cell.



Two batteries were arranged as shown in the figure. From some accidental inequality, 200 cells of the series C Z were equal to 205 cells of the series C′ Z′. When the line wire was disconnected, the two batteries were opposed, and being equal, no current passed through the galvanometer G; but when a cell was removed from either, the stronger would overpower the weaker, and a current would pass in a reverse direction through the weaker set.

When the line wire of 800 units was added to the two batteries when equal, a current from both passed through it, that from C′ Z′ deflecting the galvanometer. The number of cells in the battery C′ Z′ was now reduced from 205 to 191, when the needle showed that no current passed from it. If another cell was removed from C′ Z′ the other battery sent a feeble reversed current through it after supplying the line; if one cell was added it was enabled to assist C Z in sending a current to the line.

The resistance of the line wire was now reduced to 700 units, when 189 cells in the battery c′ z′ gave similar results, and by continuing the experiment the following table was formed:—

Number of cells in the battery c z.	Number of cells in the battery c′ z′.	Resistance of Line wire.
200 cells.	205 cells.	Infinite.
200 „	191 „	800 units.
200 „	189 „	700 „
200 „	187 „	600 „
200 „	183 „	500 „
200 „	180 „	400 „
200 „	173 „	300 „
200 „	162 „	200 „
200 „	135 „	100 „
200 „	103 „	50 „
200 „	70 „	25 „
200 „	0 „	0 „

It will be remembered that the batteries were conductors as well as producers of electricity, so that when the battery c′z′ failed to produce a current equal to that of the battery c z, it conducted part of the current of the latter. Thus, the number of cells in c′z′ accurately showed the tension of c z when sending a current through the different lengths of line wire.

The table shows that the reduction of the resistance of the line from 800 to 400 units lessened the tension of the battery c z from 200 to 180.

396. *Batteries.*

Batteries must not be placed too near a fire, or the liquids in the cells will dry up. They must be perfectly protected from frost, which stops their action.

Rosin dissolved in paraffin oil is more effective than the mixture recommended by Du Moncel (55) in preventing the formation of crystals of sulphate of zinc on the cells.

TABLES.

Size Weight and Strength of Galvanized Iron Wire.

The following table is adopted by some of the best makers, but as the quality of wire is extremely variable, it must not be implicitly relied on :—

Wire Gauge.	Diameter.	Weight of 100 Yards.	Length of 1 cwt.	Area of Section.	Breaking Weight.
No.	*Inches.*	*Lbs.*	*Yards.*	*Sq. Inches.*	*Lbs.*
4	0·240	44·00	255	0·045	3620
5	0·220	37·00	303	0·038	3040
6	0·200	30·56	361	0·031	2510
7	0·185	26·15	428	0·0265	2220
8	0·170	22·10	509	0·023	1840
9	0·155	18·36	609	0·0195	1560
10	0·140	14·97	747	0·016	1280
11	0·125	11·95	939	0·0125	1000
12	0·110	9·24	1244	0·010	800
13	0·095	7·05	1589	0·0071	568
14	0·085	5·51	2031	0·0057	456
15	0·075	4·29	2608	0·0044	352
16	0·065	3·22	3473	0·0033	264

Galvanized Iron Strand.

The strand most generally used consists of seven number 20 wires.

Gauge of Strand ...	No. 12.
Weight of one mile	122 lbs
Breaking strain ...	420 lbs

STEEL WIRE—UNGALVANIZED.

To bear the same strain, a steel wire may be 40 per cent. lighter than iron: thus, a steel wire weighing 76 lbs. per mile, is as strong as an iron wire weighing 124 lbs.

INDEX.

APPENDIX AND NOTES.

ERRATUM.

Page 70, line 9:—

For $\frac{Rr + Rf + rf}{Ef}$ *read* $\frac{Ef}{Rr + Rf + rf}$

WATERLOW AND SONS, PRINTERS, CARPENTERS' HALL, LONDON WALL.

DESCRIPTION

OF THE

TRANSLATING APPARATUS

AND

UNIVERSAL GALVANOMETER,

INVENTED BY

CROMWELL F. VARLEY.

1863.

In the following pages will be found a full description of my method of arranging the Translating Apparatus. The system of working by the reversal of the battery currents renders the relays self-adjusting; consequently the variation of the strength of the currents from humidity of the insulators, &c., seldom necessitates any alteration in the adjustment of the relays.

The Translating Apparatus is adapted to this system, and is universally made use of by the Electric and International Telegraph Company.

The construction of my Universal Testing Apparatus, and its application to the various modes of testing the condition of over-ground, subterranean, and submarine wires, and for ascertaining the locality of faults in either of them, is also fully described, and diagrams given which illustrate the various connections necessary for each particular test.

C. F. VARLEY.

October 20th, 1863.

DESCRIPTION OF

C. F. VARLEY'S

TRANSLATING APPARATUS.

This apparatus consists of two complete sets of printing instruments, each composed of a Morse machine, two relays, a spacing apparatus, two switches, a galvanometer, and a key. The two sets, as will be seen by the diagrams, are connected with each other in such a manner as that either may be used separately as a terminal instrument, or the two combined as a translating apparatus.

The Morse machine is precisely similar to those in ordinary use for printing circuits, consisting of a pair of rollers put in motion by clockwork, carrying the strip of paper between them. In the upper one is a groove, in which the style or embossing point of the movable armature plays. Under the pallet of the armature are placed the coils of an electro-magnet. When a current is sent through the coils the armature is depressed at one end and raised at the other;

the latter carrying the style embosses the paper as it is drawn forwards by the rollers.

The relays—one used for closing the marking circuit, the other for closing the spacing circuit—are composed of a horizontal bar electro-magnet, which is movable within its coils, which are ordinary cylindrical ones, separated into two parts to allow the axis of the bar to pass through; each end of the bar plays between the poles of a permanent horseshoe magnet, each magnet being similarly placed in respect to its poles. When a current passes through the coils the movable soft iron core is deflected to the one side or the other, according to the way in which it is magnetized. When the current which is intended to mark the paper is sent through the marking relay, the bar is deflected against a metallic point which is in connection, as shown in the diagram, with the zinc pole of the local battery, the bar itself being connected to the copper pole. When on the passage of a current through the coil the bar is deflected as above, the local circuit is closed; the armatures on the levers of the Morse machine and spacing apparatus being simultaneously drawn down, as hereafter explained.

The spacing apparatus consists of an electro-magnetic coil, with an armature and pallet supported on an axis above it, and furnished with two pillars, with adjusting contact screws to limit its upward and downward motion.

The line switches are for the purpose of dividing the line, if necessary, so that the translating station can communicate with any station on the up or down line separately. This is accomplished when the switch handles are turned to the right (I Q, *vide* fig. 1). When in the other position, viz., to the left (D F), the keys are taken out of circuit, and both line wires are connected to the translators, so that the distant stations can communicate with each other.

When receiving a message, or translating, the handles of the key switches are placed to the right (*receive*); but when signals are required to be sent by the translating station, the handles must be turned to the left (*send*).

The galvanometers are provided with two separate coils of wire, so that the outgoing current, which is strong, may pass through only a short coil, and the receiving current, which is comparatively weak, through a longer one, thus making the galvanometer show the force of either current. The shorter coil may be cut out of circuit entirely by the insertion of a plug provided for that pnrpose.

The keys are used for the transmission of currents either way, when the line switches are at "I Q," and the key switches at "*send*."

The induction plates are composed of lead or carbon, charged with diluted sulphuric acid, and when once charged require no renewal, except what is necessary to compensate for evaporation. They give no current of themselves, but are capable of receiving an induced charge. If a galvanometer be inserted in the circuit immediately after passing a current through them, a strong deflection will be observed; but this will gradually decrease in strength until it nearly disappears, the use of these are explained further on.

The whole apparatus may be worked from one main set of batteries (as in fig. 1), or separate sets may be employed if preferred. If the former plan be adopted, the batteries must be unequally divided; the copper pole of the larger or positive battery, and the zinc pole of the smaller or negative battery, must be led to the apparatus, the other poles being put to earth.

In fig. 1 the whole of the connections of both sets of apparatus are fully shown. Fig. 2 gives the connections brought into use when a *down* station, working with a nega-

tive marking current, sends to an *up* station. Fig. 3 shows the connections used when an *up* station, working with a positive marking current, sends to a *down* station.

Fig. 4 shows the course of the marking current received from an *up* station, and fig. 5 gives the route of the marking current received from a *down* station.

Figs. 6 and 7 show the translating arrangements; but as the arrangement is similar in both, it will suffice to explain the former, after which the latter will be easily understood.

Assuming, then, that the up station is transmitting a current along the line, and also that the line switches are turned to the left (D F), in a position for translating, and let the current be a marking one (*i.e.* a positive current): coming from the up line it enters the shorter of the two separate coils of the galvanometer of No. 1 set, thence it goes to the line switch, from which it passes passively through the Morse machine and the spacing apparatus of No. 2 set, and back to the marking relay of No. 1 set, through the coil of which it passes; thence it goes through the coil of the spacing relay in a reverse direction, and finally passing through the longer coil of the galvanometer, it makes its escape to the earth.

In passing through the coil of the marking relay of No. 1 translator, the current deflects the armature, and closes the local circuit, which causes the armatures of the Morse machine and spacing apparatus to descend simultaneously. The armature lever of the Morse machine being connected, through the galvanometer and line switch, with the down line, and the pillar which limits the downward motion being connected to the copper pole of the relaying battery, when the armature descends a current is transmitted on to the down line, marking the paper at the distant station. During this time, although the armature of the spacing apparatus

has been drawn down, it has sent no current; but when the armature of the Morse is released by the sending station reversing the line current, the spacing apparatus comes into play and transmits a current the reverse of that before sent by the Morse machine.

The local circuit is arranged thus:—When the armature of the marking relay is deflected, the current from the local battery passes through the coil of the Morse machine and that of the spacing apparatus. On its arrival at the latter it is divided, one portion going through the coil of the spacing apparatus, and the other portion through the induction plates, which are placed in a loop on the coils of this part of the translator. When the distant station reverses the current, by allowing his key to ascend, the armature of the marking relay is deflected back to the non-conducting point, breaking the local circuit, in consequence of the line current traversing the coil in a contrary or reverse direction; but as the line current passes round the spacing relay in the opposite direction, the armature of this relay is now deflected, and permits the current from the local battery to pass through the coil of the spacing apparatus (and the induction plates) only, when the armature of the spacing apparatus only is depressed, while that of the Morse machine is elevated, connecting the down line to the zinc pole of the smaller battery. In this way reverse currents are translated from station to station.

The use of the induction plates is this:—When the local circuit is broken, the induced current from the leaden plates holds down the armature of the spacing apparatus for a short interval, and thus prevents it rising during the reversal of the current.

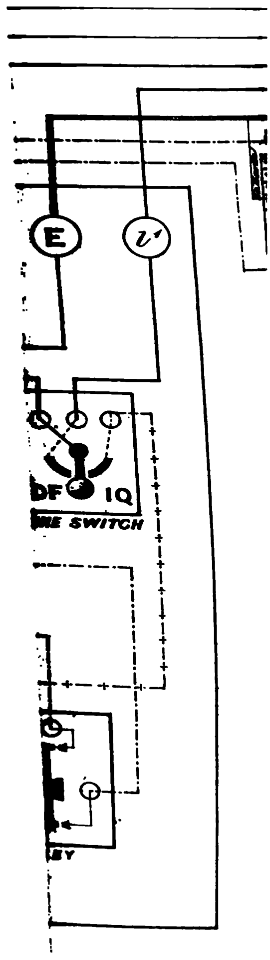
To recapitulate:—When a distant station transmits a marking current (copper, for instance), the armature of one

of the relays is actuated, and the local current passes through the coil of the magnet of the Morse machine, and then divides itself between the coil of the spacing apparatus and the induction plates, the Morse machine transmitting a copper current on to the distant station. During this time the spacing apparatus is ready to perform its part in sending on a negative current, but cannot do so until the sending station reverses his key: this done, the armature of the spacing relay is then deflected, and allows the spacing apparatus to act alone, and transmit a zinc current. By the addition of the induction plates to the coil of the spacing apparatus the armature is kept down and in readiness to send the zinc current, instead of retiring at each break of the line current as it otherwise would do.

The diagrams explain themselves.

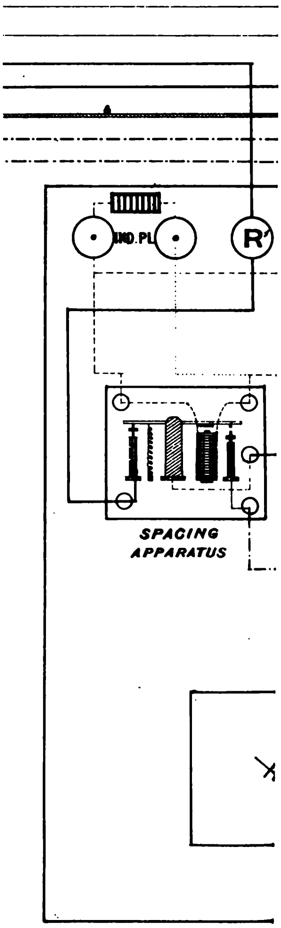
WATERLOW AND SONS, CARPENTERS' HALL, LONDON WALL.

F I G.



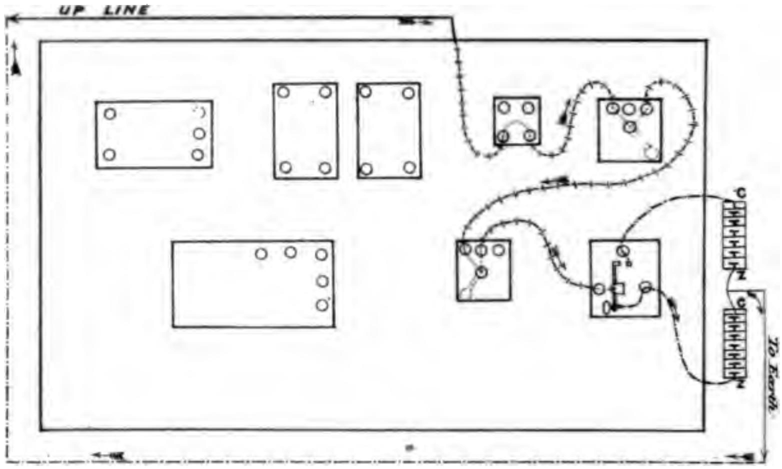
. VARLEY'

I.



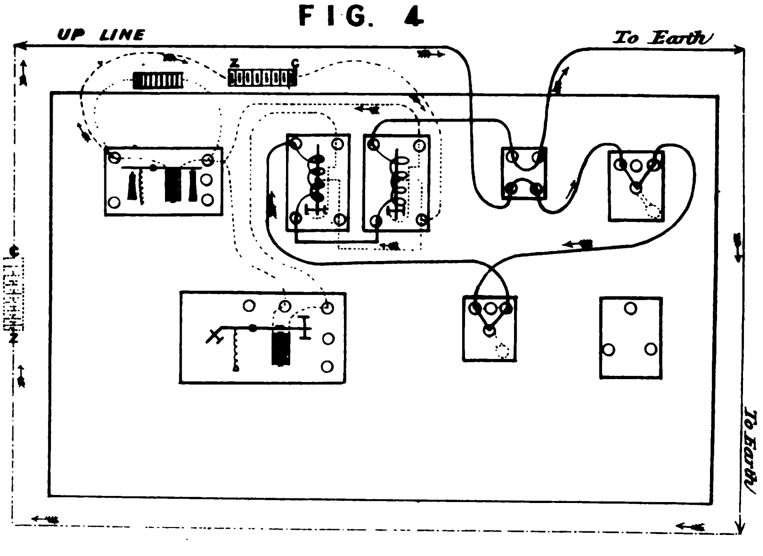
NSLATORS

FIG. 2



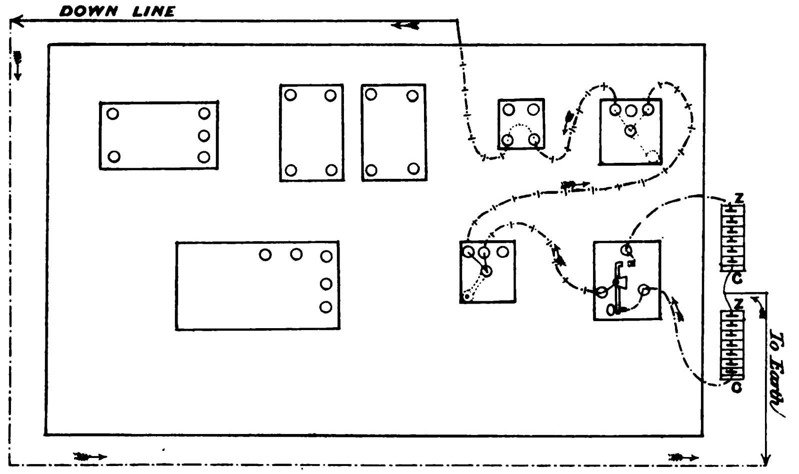
SENDING TO AN UP STATION

FIG. 4



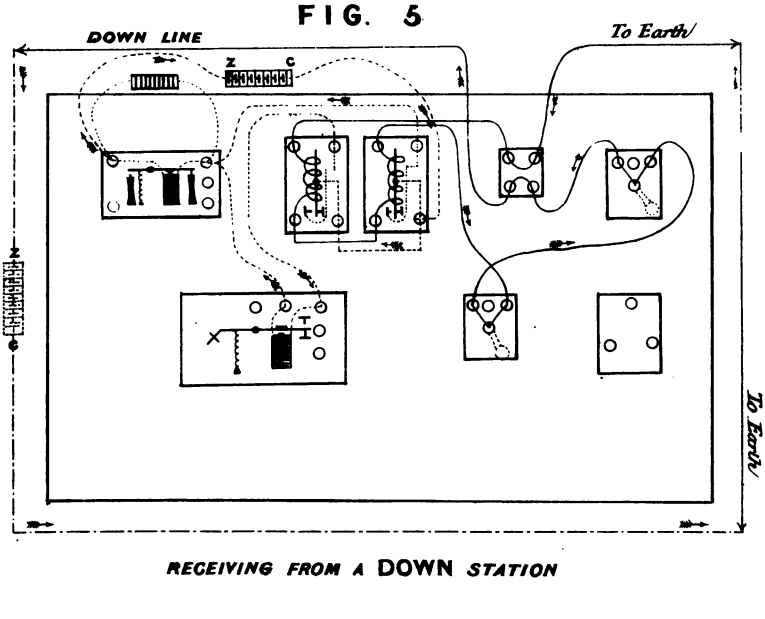
RECEIVING FROM AN UP STATION

FIG. 3



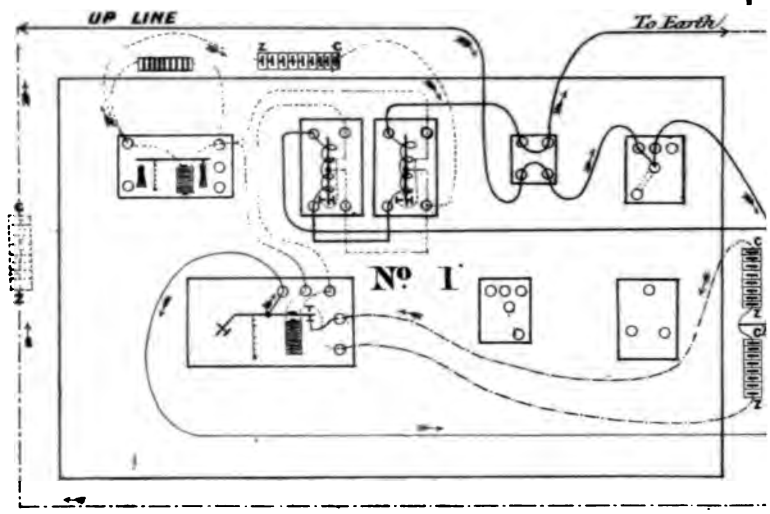
SENDING TO A DOWN STATION

FIG. 5



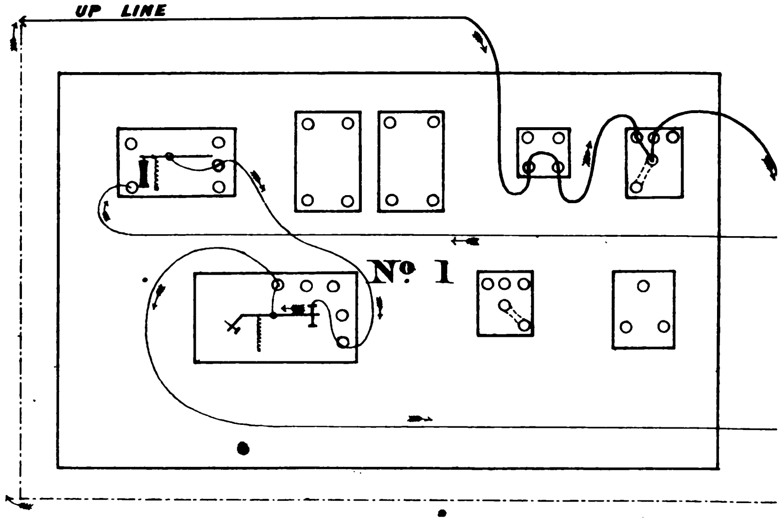
RECEIVING FROM A DOWN STATION

F



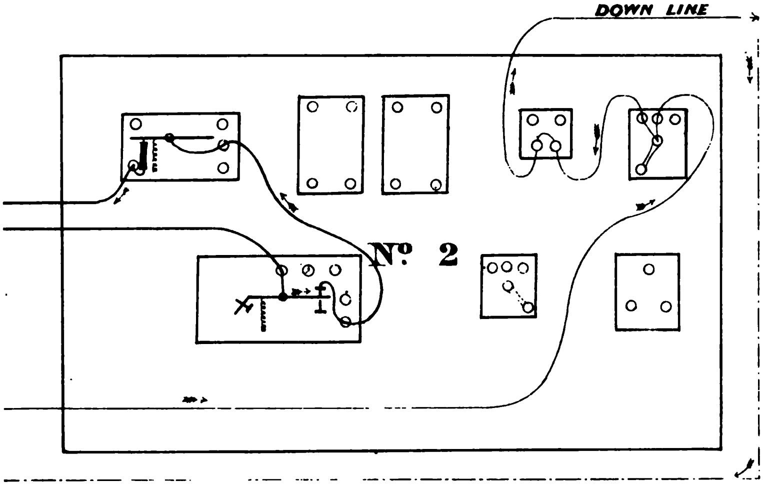
UP STATION WORKING THROUGH DIRECT TO DOWN STATIO

F I



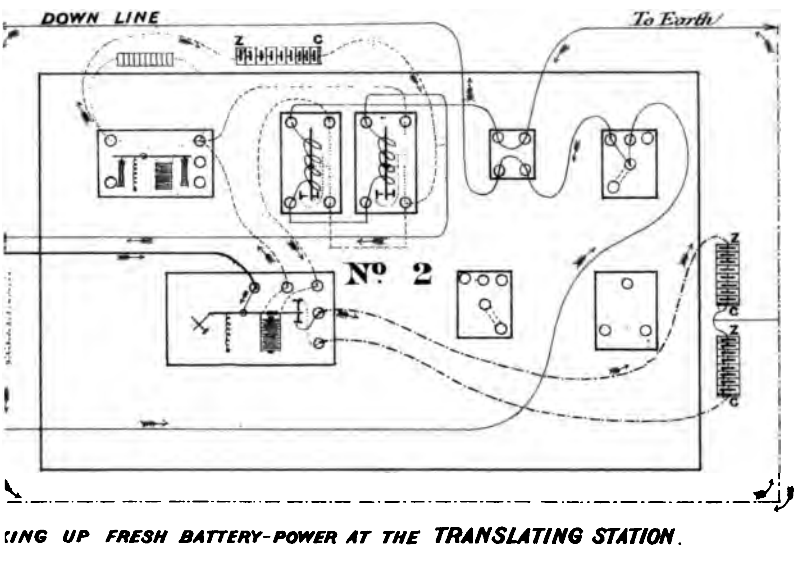
DOWN STATION WORKING THROUGH DIRECT TO UP STATIO

6



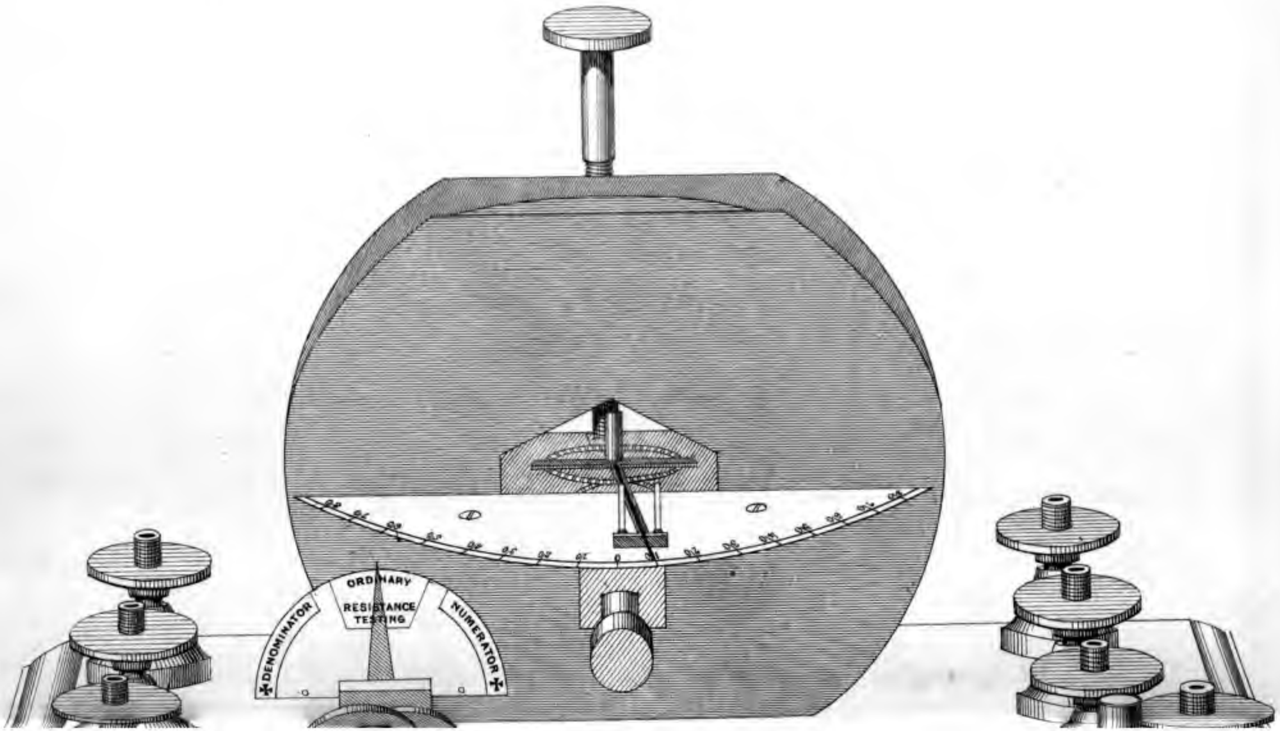
KING UP FRESH BATTERY-POWER AT THE TRANSLATING STATION

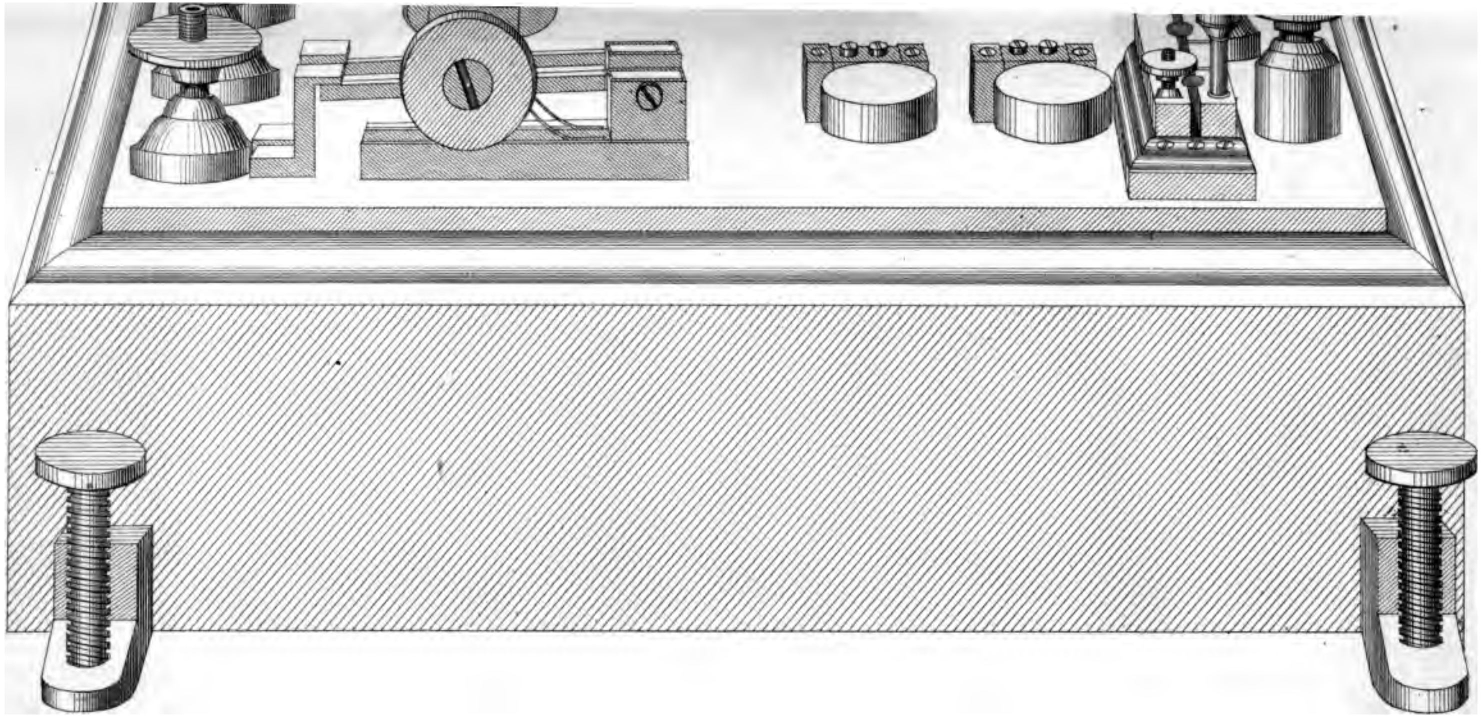
7



ING UP FRESH BATTERY-POWER AT THE TRANSLATING STATION.

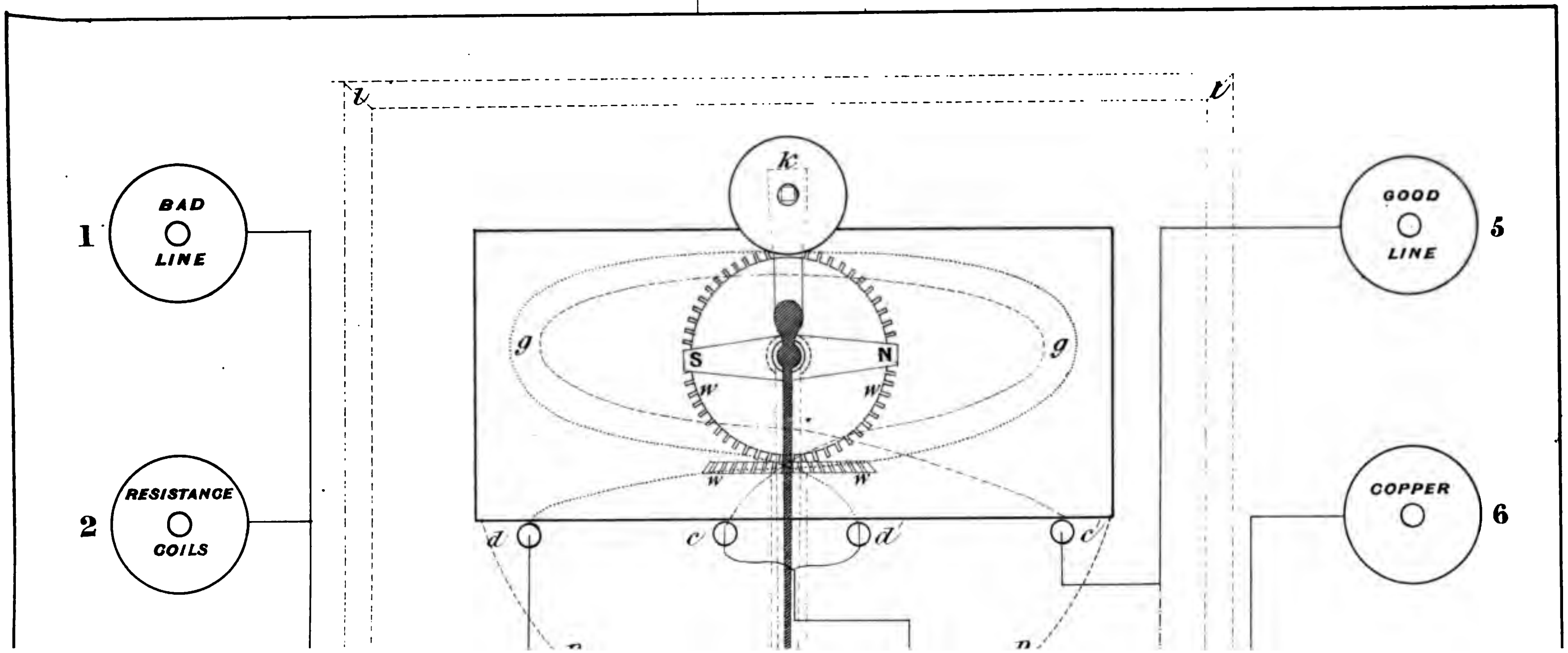
FIG. I.





EXTERNAL APPEARANCE OF THE GALVANOMETER

FIG. 2.



1
BAD
LINE
2
RESISTANCE
COILS
GOOD
LINE
5
COPPER
6
k
S
N
g
g
w
w
w
w
d
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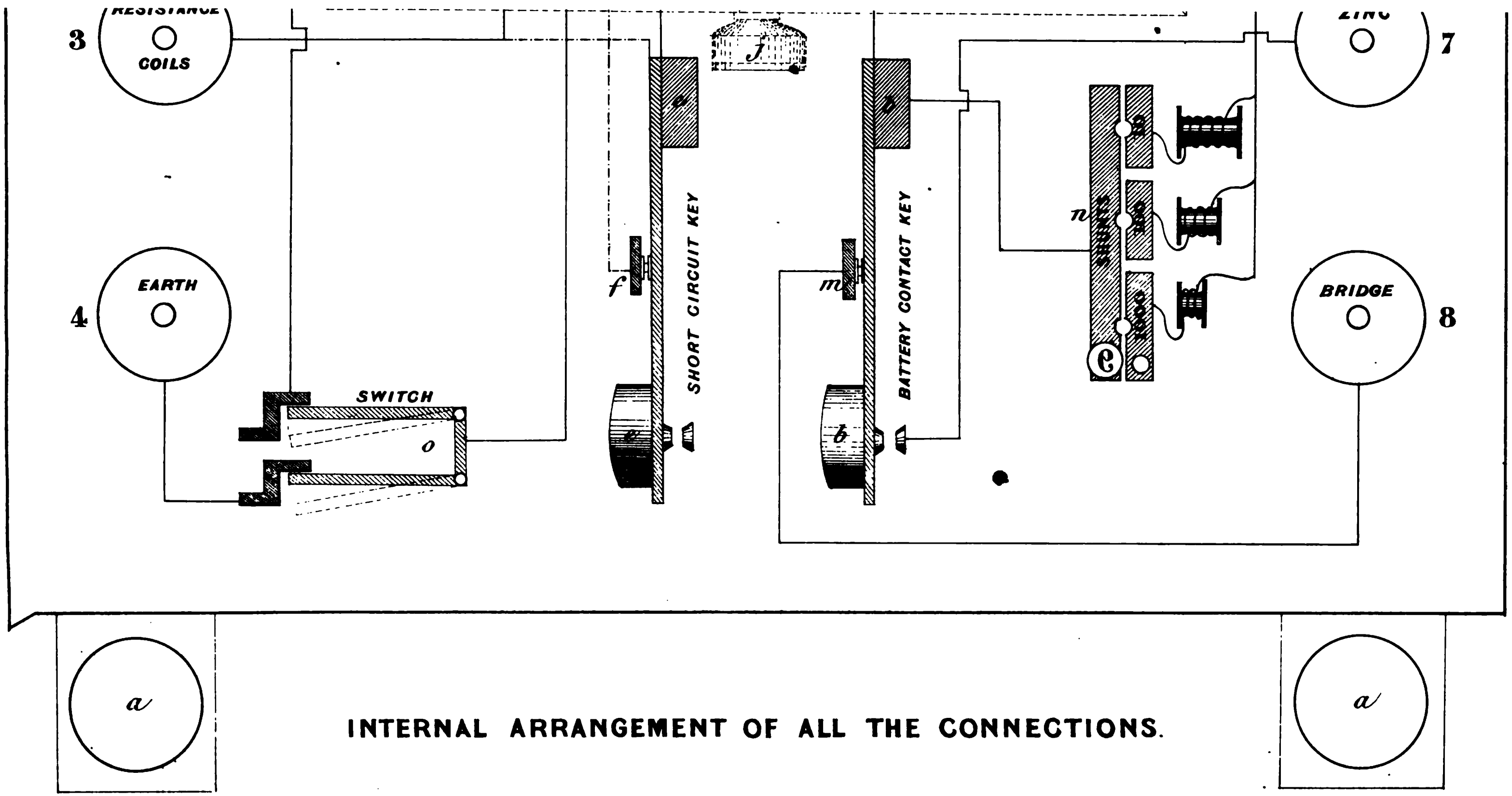
d'
c'
t
t'



INTERNAL ARRANGEMENT OF ALL THE CONNECTIONS.

INSTRUCTIONS

FOR THE USE OF

C. F. VARLEY'S

UNIVERSAL TESTING APPARATUS.

THE apparatus consists of a differential galvanometer; a switch with three positions, marked respectively, "NUMERATOR" when turned to the right, "DENOMINATOR" when turned to the left, and "ORDINARY RESISTANCE TESTING" when vertical. There are two keys and three shunts mounted on a board, with one small and eight large terminals, *vide* figures 1 and 2.

Figure 1 is a perspective view of the instrument.

Figure 2 is a skeleton view, showing the connections.

Figures 3 to 13 show the arrangement of the apparatus for the several tests hereafter explained.

Figure 2.

a a a three screws for levelling the instrument.

g g a galvanometer coil, which is wound with two wires *c c′* and *d d′*, so connected that the currents are made

to traverse them in opposite directions. Each of these two circuits consists of 2,856 convolutions of silk-covered wire, ·00581 diameter. Each circuit giving a resistance of 36 Varley units.

S N a magnetic needle inside this coil, mounted upon a point: to this is attached an indicator, *h*, playing between the pins *i i*, which limit its motion.

p p is a dial divided into degrees to enable the deflection to be read off.

j is a milled nut attached to a bevel wheel, *w w*, by turning which *i i* can be moved to the right, or to the left.

k is a screw which, when screwed downwards, lifts the magnet S N off its point, to preserve the latter from becoming blunted during carriage. The milled handles *j* and *k* are squared on to their axes, and can be pulled off when it is necessary to remove the case *l l l l*.

b is the battery key which, when depressed, connects the zinc pole of the battery with the two wires of the galvanometer coils marked *c* and *d'*.

c and *d* are the other ends of the two wires of the galvanometer coils; *d* is connected to terminal No. 3 and to the short circuit key *e* as shown by the dotted line. *c'* is connected to terminal No. 5 and to the bridge *f*, as shown by the dotted line. When the short circuit key is *not* depressed, any current sent through the galvanometer divides equally between the two wires, and consequently produces no action upon the needle.

m is a bridge over the battery key *b* connected to terminal No. 8.

n is a series of shunts which can be brought into play

by inserting the plug into one of the holes marked 10, 100, 1000, so as to shunt off a portion of the current that would otherwise pass through the galvanometer wire marked $d\ d'$, and thus reduce the action on the needle 10, 100, or 1000 times. The resistance of each of the wires of the galvanometer coils is equal to 36 Varley units; the resistance of the 10 shunt is 4 Varley units, that of the 100 shunt is $\frac{4}{11}$ of a Varley unit, and that of the 1000 shunt is $\frac{4}{111}$ of a Varley unit.

o. A switch with three positions, marked NUMERATOR, ORDINARY RESISTANCE TESTING, and DENOMINATOR. When turned towards NUMERATOR, the copper pole of the battery is connected to terminal No. 4; when turned to ORDINARY RESISTANCE TESTING, it is connected to terminals Nos. 1, 2, and 4; and when turned to DENOMINATOR, it is connected with terminals Nos. 1 and 2 only.

To use the apparatus turn the screw *k* until the needle rests upon its point, then twist the apparatus round until, through the influence of terrestrial magnetism, the pointer *h* stands at zero. The apparatus is now ready for use.

This instrument is used in connection with a series of resistance coils, which are usually constructed with resistances 0.1, 0.2, 0.3, 0.4, 1, 2, 3, 4, 10, 20, 30, 40 and 100 units, in addition to a disconnecting space marked *infinite*.

By inserting the plugs into the various holes, the ends of the resistance coils corresponding to the various numbers are connected together and cut out of circuit. By adding together the respective resistances of those coils still left open, the amount of resistance will be ascertained.

The leading peculiarity of this machine is, that it indicates the distance of a leak or "earth" without calculation—the

distance being shown in a fraction of the length of the line, in cases where a perfect wire of equal resistance to the faulty one is available for the formation of a loop: *vide* fig. 3.

Designate your own station by A, and the station beyond the fault by B. The latter must be instructed to connect the two wires together in a loop, as shown in fig. 3.

Connect the apparatus as follows:—The good line to terminal No. 5, and the leaky wire to No. 1, then join the battery, the earth, and the resistance coils as shown in fig. 4, where C Z is the battery, R the resistance coils, and E the earth. Then take the NUMERATOR test as follows. Turn the switch to the right towards NUMERATOR, depress the short circuit key *e*, and twist the instrument, if necessary, until the indicator stands at zero; now depress both keys and vary the resistance of the resistance coils until the needle stands at zero; repeat this several times to get it correct. Set this amount down as a *numerator.*

Now turn the switch to the left hand towards DENOMINATOR (fig. 5), readjust, if necessary, the instrument to zero when the short circuit key *e* is depressed, then depress both keys and insert resistance until the indicator again stands at zero. Set this amount down as a *denominator,* and the fraction so obtained indicates the distance of the fault from the station B, the line being considered as unity. If the distance be required in *miles,* multiply the numerator by the length of the line, and divide it by the denominator; the quotient gives the distance of the fault from B in miles.

The resistance of the numerator represents the resistance of the loop beyond the fault E (fig. 3)—viz., that of the portions of the lines marked *y y*.

The resistance of the denominator represents the whole resistance of the two wires from A to B and B to A.

Theory of the above:—

Resistance of each wire between A and B $= x + y = s$
Distance of fault from A $= x$
Do. do. B $= y$

In the first test the resistance r is necessary to make $x = s + y$ $\Big\} = (\textit{numerator}) = r$

In the second test the resistance of the two wires between A and B is obtained $\Big\} = (\textit{denominator}) = 2s$

$$x + r = s + y = x + 2y$$

$$r = 2y$$

$$\text{And } \frac{r}{2s} = \frac{2y}{2} = \frac{y}{s} = \frac{\text{“}\textit{numerator}\text{”}}{\text{“}\textit{denominator}\text{”}}$$

To FIND THE RESISTANCE OF A SINGLE WIRE turn the switch to "ORDINARY RESISTANCE TESTING." Connect the wires as shown in figure 6, and insert resistance by removing the plugs of the resistance coils as before until the needle of the galvanometer stands at zero. The resistance necessary to effect this is equal to the resistance of the line. When the conductivity of a wire is required, it must be joined to earth at the distant end. To test the resistance of insulation, simply disconnect the wire and proceed in the same manner.

When the resistance of the coils is insufficient to measure the line, insert the shunt at 10, 100, or 1000. These shunts are so proportioned as to shunt off $\frac{9}{10}$, $\frac{99}{100}$, or $\frac{999}{1000}$ of the current that would otherwise pass through the wire of the galvonometer connected with the resistance coils, and the result is equivalent to multiplying the resistance shown by the coils 10, 100, or 1000 times according to the shunt used.

CHARGE AND DISCHARGE, OR RETURN CURRENT: *vide* figure 7. Connect the terminal No. 8, by means of a piece of wire, with terminal No. 4, and the latter to the earth, in

order to connect the bridge *m* over the battery key *b* with the earth. The distant end of the line must be disconnected, and the testing end connected to the terminal No. 3.

To measure the *charge* lift the pointer *h* out of the stops *i i*, taking care to put it on the right side, so as to be free to swing; depress the key *e* and then depress the key *b*, and note the swing of the needle, which will indicate the charge. If there be no perceptible leakage on the line the needle will speedily return to zero.

To measure the *discharge*, or return current, place the indicator *h* on the other side of the stops, depress first the key *b* to charge the line, next depress the key *e*, then let the key *b* fly up to its bridge *m*, and note the swing caused by the return current. If the line be not perfectly insulated the return current will not be so powerful as the charge. By observing this difference, a pretty good idea of the *true* charge and discharge, which should be alike, may be obtained. In these tests the permanent deflection of the needle, if any, should be carefully noted.

When taking these tests the battery power must be so regulated that the needle shall not be thrown beyond the range of the scale.

To COMPARE TWO WIRES note the deflection obtained from the shorter wire with any given battery power, then reduce the battery power until the second or longer wire gives the same amount. The lengths of these two wires are to each other inversely as the number of cells used in each case (very nearly). These charges and discharges, from their suddenness, are very apt to demagnetize or cross-magnetize the needle, when irregular results will be obtained.

DIFFERENTIAL METHOD OF TESTING THE CHARGE AND DISCHARGE OF TWO WIRES:

This method being the most accurate, should invariably be

adopted where possible. Ascertain by the previous test which of the two wires gives the greater charge and discharge. Connect this wire, as in figure 8, to terminal No. 3, and the other wire to terminal No. 5. Connect the battery as usual to terminals Nos. 6 and 7, and earth to Nos. 4 and 8. Connect resistance coils to the small shunt terminal No. 9 and terminal No. 3. Switch vertical towards ORDINARY RESISTANCE TESTING.

To measure the charge, depress the short circuit key e, then depress the battery key b, and insert plugs into the resistance coils until that portion of the charge into the longer wire which traverses the one coil of the galvanometer is made equal to the charge going into the shorter wire through the other coil, which will be indicated by the needle remaining at zero when the key b is depressed.

The following formula will then give the comparative charge and discharge:—

Let s = the resistance inserted as the shunt,
g = that of one coil of the galvanometer (36 units),
e' = the charge or discharge of the short line,
e = the charge or discharge of the long line,
then $s \;:\; s+g \;::\; e' \;:\; e.$

If the two wires tested be of equal dimensions in every respect excepting length, the length of the unknown wire can be inferred from the known wire by the above formula; thus, if the length of the *shorter* wire be known, multiply it by $s+g$ and divide by s, which gives the length of the longer wire; or, if the length of the *longer* wire be known, that of the shorter may be obtained by multiplying the longer length by s and dividing by $s+g$, ($\frac{s+g}{s}$ being the multiplying power of the shunt used).

To PROVE THE ACCURACY OF THE GALVANOMETER, RESISTANCE COILS AND SHUNTS:

These should be frequently tested, as they are sometimes injured by high battery power, &c., &c.

Connect the resistance coils R, as shown in figure 9, between terminals Nos. 2 and 3. Loop terminals Nos. 1 and 5. From terminal No. 4, which is in connection with the copper pole of the battery, lead a wire to resistance coils at *r*. Turn the switch to NUMERATOR.

To test the galvanometer to see that the two wires balance each other; having inserted all the plugs into the resistance coils, depress the battery key *b* without touching the short circuit key *e*, and if the needle remains stationary the coils are exactly balanced; if the needle moves, ascertain how much resistance must be added to the one side or the other when both keys are depressed to make the needle stand at zero: this will show the difference of the resistance of the two coils.

To test the resistance coils compare the tenths of a unit with each other by putting ·1 and ·2 on one side of *r* and ·3 on the other, depress both keys, and if they be equal the needle will not move; ·3 + ·1 will test ·4, and ·1 + ·2 + ·3 + ·4 will test 1 unit. In this way, by combination, all the coils can be tested against each other.

To test the shunts insert the 10 shunt pin, as in figure 9, put ten units between the terminal No. 3 and *r*, 100 between *r* and terminal No. 2; if the needle does not move the shunt is correct.

To test the 100 shunt, insert one unit between No. 3 and *r*, and 100 between *r* and No. 2, and proceed as in last case.

To test the 1,000 shunt, insert ·1 between No. 3 and *r*, and 100 between *r* and No. 2. and proceed as before.

TESTING THE RESISTANCE OF BATTERIES.

TO FIND THE RESISTANCE OF A SINGLE CELL. Place the switch to "ORDINARY RESISTANCE TESTING," and connect the zinc plate of the cell to No. 7 terminal, and the copper plate to No. 5 terminal, as in figure 10, depress both keys, and observe what deflection is thus obtained through the one coil of the galvanometer.

Then connect, as shown in figure 11, the copper plate to No. 5 terminal, the zinc plate to No. 1 terminal, and the resistance coils between Nos. 2 and 3, (switch still vertical) depress the short circuit key *e*, and see how much resistance is necessary to produce the same deflection as previously obtained by the arrangement in figure 10, and this resistance is equal to that of the single cell, for, in the first place, we have one cell with the resistance of the battery and one coil of the galvenometer in circuit giving a certain deflection: in the second place the same deflection is produced with one-half the electricity traversing twice the number of convolutions of wire round the needle S N, and if

n = number of convolutions of each wire of the galvanometer,

g = the resistance of each wire of the galvanometer,

x = the resistance of the single cell,

r = the resistance inserted in the second case to obtain the same deflection as in the first case,

then, $\frac{n}{x+g}=\frac{2n}{x+2g+r}$ or $2x+2g=x+2g+r \quad \therefore x=r$,

i.e. the resistance inserted (fig. 11), equals the resistance of the cell.

To test the resistance of a whole battery.

Firstly.—Loop together terminals Nos. 3 and 4 (fig. 12), connect the battery between Nos. 6 and 7, turn switch to NUMERATOR, and insert a shunt, so as to produce a deflection on depressing both keys, within the range of the instrument. It will easily be seen which shunt is necessary to do this. Note accurately the deflection produced, and this will be the result of the electro-motive force of the whole battery divided by the resistance of the battery, added to the resistance of the shunt and one wire of the galvanometer coil when combined, (and which is, of necessity, less than the least of these two resistances).

Let n be the number of cells used,

x the resistance of each cell,

g the resistance of one wire of the galvanometer coil (36 units),

s the resistance of the shunt used,

$$\text{then, } \frac{n}{n\,x + \dfrac{g\,s}{g+s}} = \text{I}$$

Secondly.—Proceed as shown in figure 13, place the switch towards ORDINARY RESISTANCE TESTING, and the resistance coils between Nos. 2 and 3; take out the shunt plug, and connect *one cell* only of the battery tested between Nos. 6 and 7. Depress both keys and add resistance until the deflection equals that obtained in the previous test, figure 12.

This deflection will be the result of the electro-motive force of one cell divided by the resistance of one cell x, added to that of one wire of the galvanometer coil g, and the resistance inserted r, as in the following formula :—

$$\frac{1}{g + x + r} = \text{I}'$$

the current passing through the galvanometer coil being the same in both cases, $\text{I}\ \frac{s}{g + s} = \text{I}'$

and, $\dfrac{n}{n\,x + \dfrac{g\,s}{g+s}} : \dfrac{1}{g + x + r} :: \dfrac{g + s}{s} : 1$

from which may be obtained the formula—

$\left(\frac{g + r}{g} - \frac{1}{n}\right) s = x$, the resistance of each cell.

For example: if in the first case 10 cells be tested, the 100 shunt be used, and a deflection of say 20° be obtained; and in the second case when one cell is used 17·1 units are necessary to obtain the same deflection of 20°; then, as g equals 36 units, r equals 17·1 units, n equals 10, and s equals $\frac{4}{11}$ of a unit, we get

$$\left(\frac{36 + 17{\cdot}1}{36} - \frac{1}{10}\right) \times \frac{4}{11} = x,$$

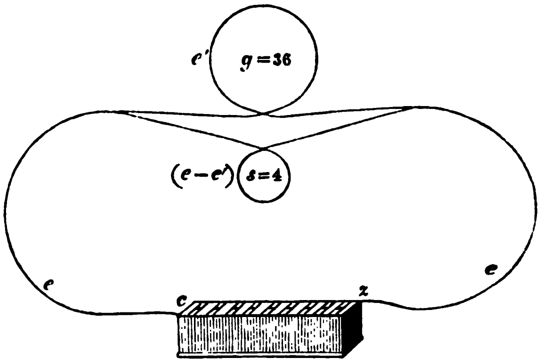
or, $x = \left(\frac{53{\cdot}1}{36} - 0{\cdot}1\right) \times \frac{4}{11} = 1{\cdot}375 \times \frac{4}{11} = \frac{5{\cdot}5}{11} = {\cdot}5$

the resistance of each of the cells tested.

On the amount of current traversing the galvanometer when shunts are used.

In the following figure let e be the electro-motive force of the battery employed, g the resistance of the galvanometer coil, e' the current going through g, s the resistance of the shunt, and $e - e'$ the current going through s.

Then $e' + (e - e') = e$, and the current traversing each portion of the circuit will be inversely as their resistance;



that is to say, $e' : e - e' :: \frac{1}{g} : \frac{1}{s}$

$$\frac{e-e'}{g} = \frac{e'}{s}$$

$$(e-e')\,\frac{s}{g} = e'$$

$$\frac{e-e'}{e'} = \frac{g}{s}$$

$$\therefore \frac{e'}{e} = \frac{s}{g+s}$$

If $e = 1$ the amount of current going through the galvanometer, g will be $\frac{s}{g+s}$, and as the respective resistances of the shunts are 4, $\frac{4}{11}$ and $\frac{4}{111}$, and that of the galvanometer 36 units, the amount of current going through the galvanometer when they are respectively introduced will be

$$\frac{4}{36+4} = 0{\cdot}1; \quad \frac{\frac{4}{11}}{36+\frac{4}{11}} = 0{\cdot}01; \text{ and } \frac{\frac{4}{111}}{36 \times \frac{4}{111}} = 0{\cdot}001;$$

and therefore the multiplying powers of the shunts are respectively 10, 100 and 1000.

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FIG. 3

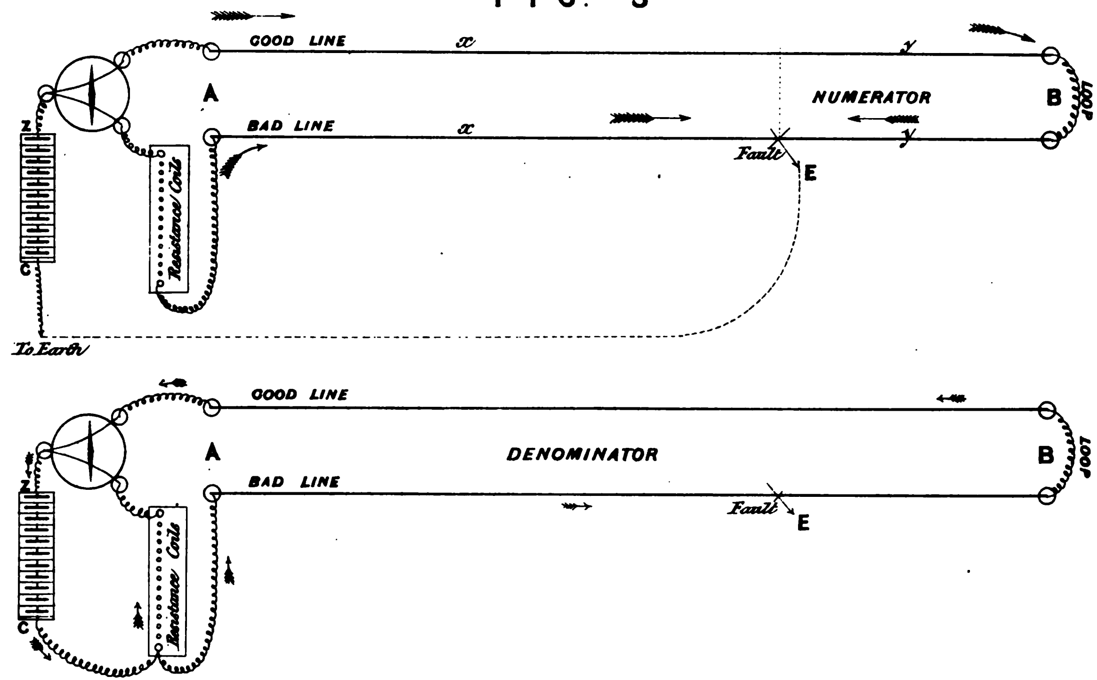
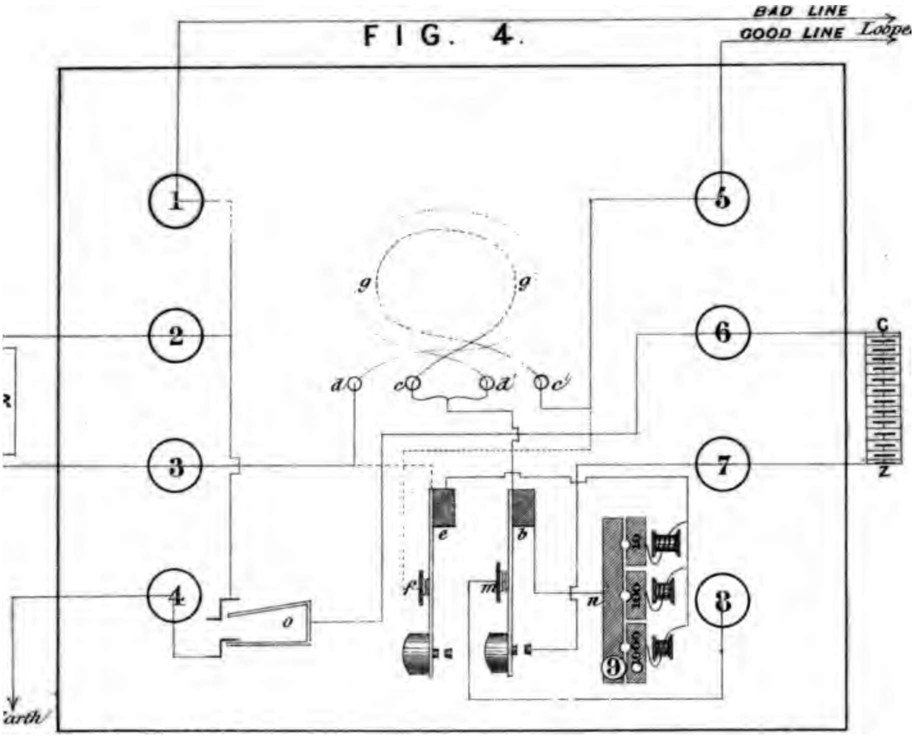
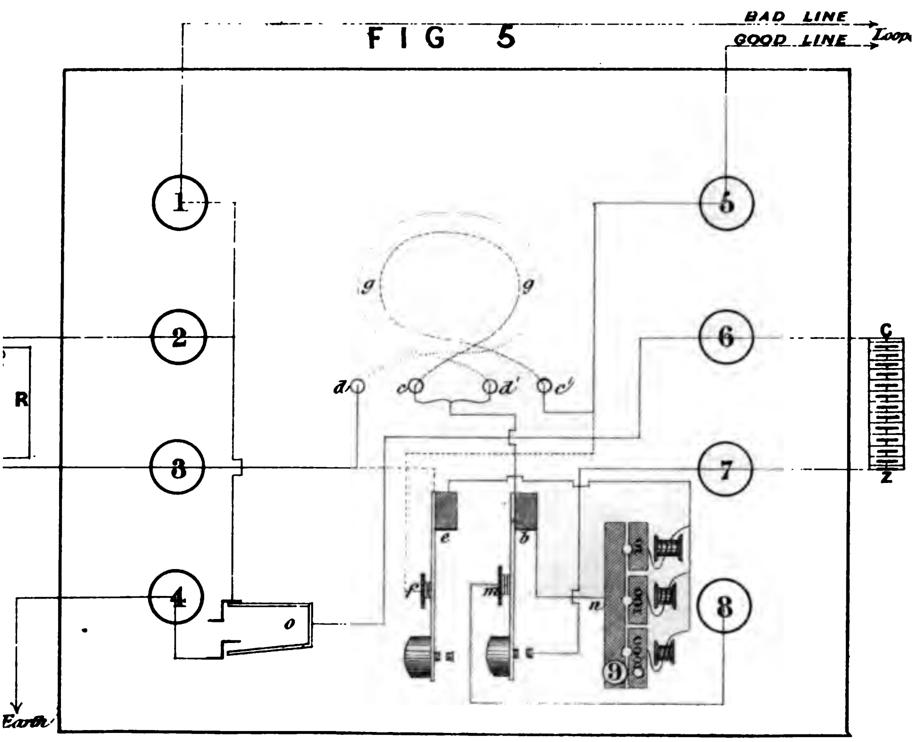

GOOD LINE
BAD LINE
A
B
LOOP
x
y
NUMERATOR
Fault
E
To Earth
Resistance Coils
Z
C
GOOD LINE
BAD LINE
A
B
LOOP
DENOMINATOR
Fault
E
Resistance Coils
Z
C

FIG. 4.



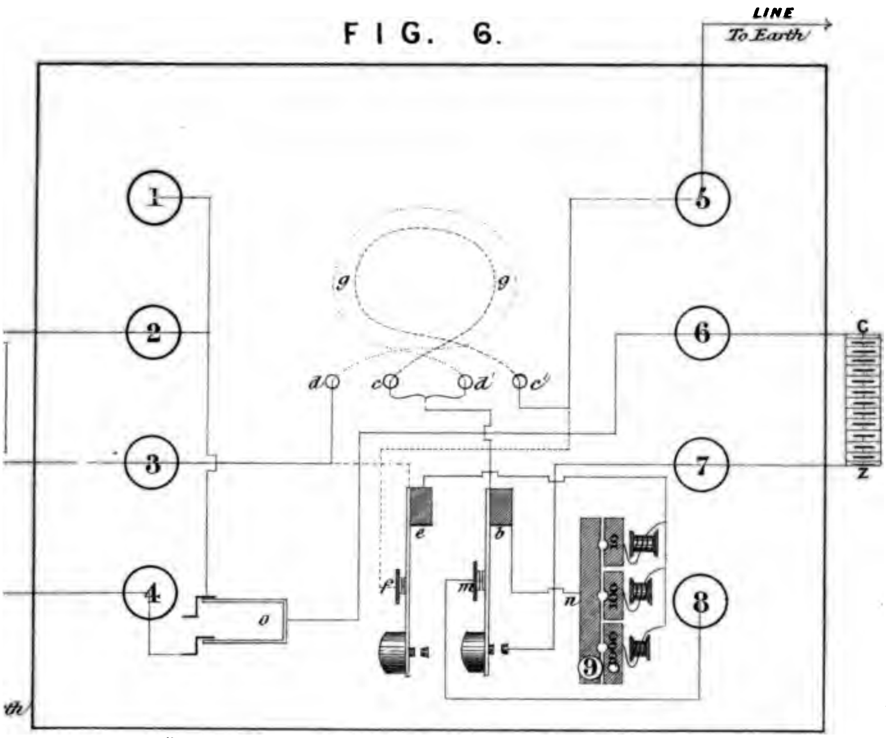
"NUMERATOR"
Switch turned to the Right

FIG 5



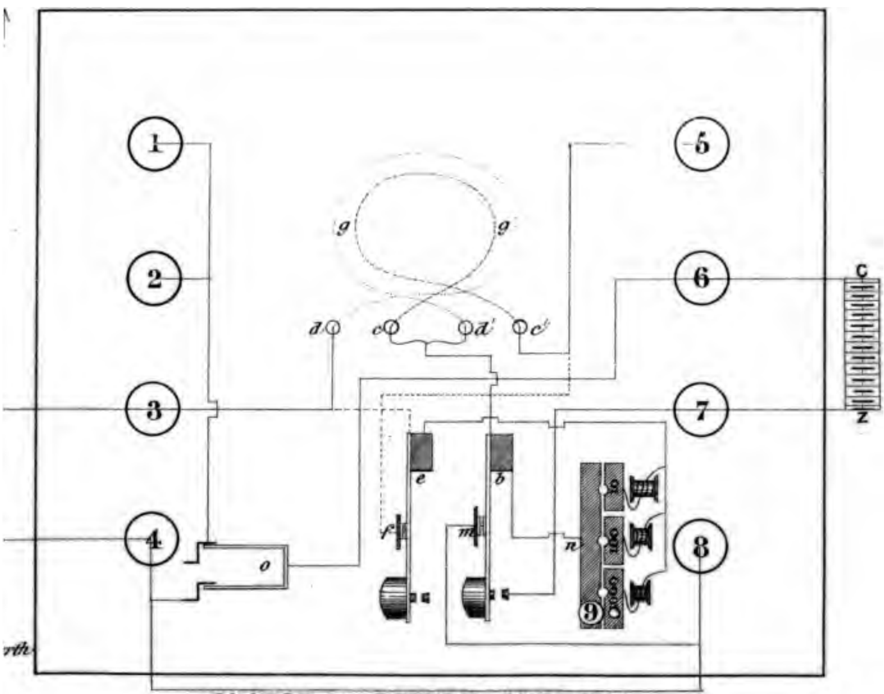
"DENOMINATOR"
Switch turned to the Left

FIG. 6.



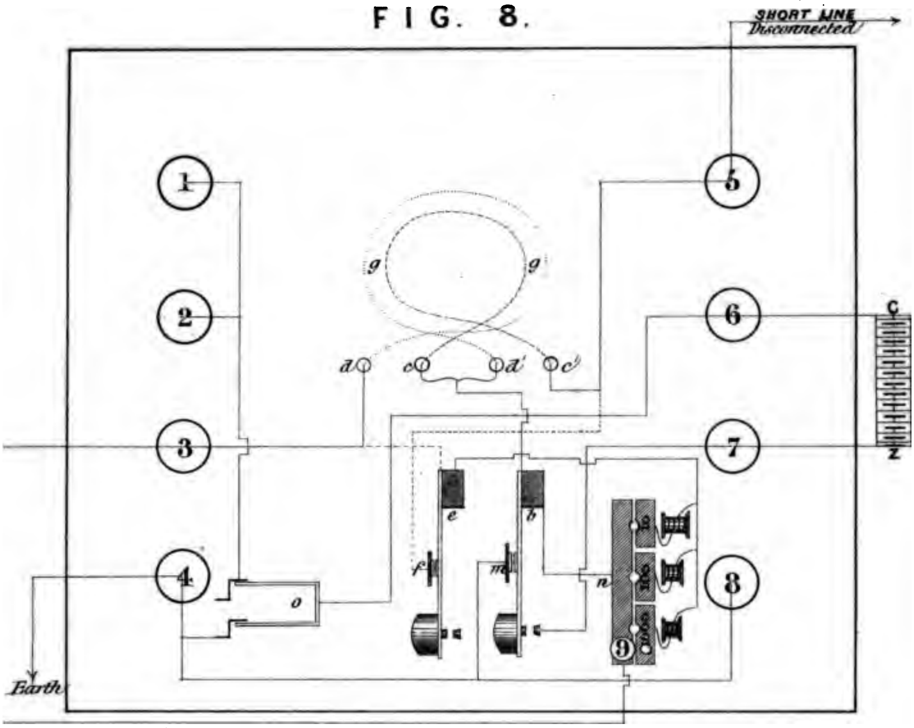
"ORDINARY RESISTANCE TESTING"
Switch vertical

FIG. 7.



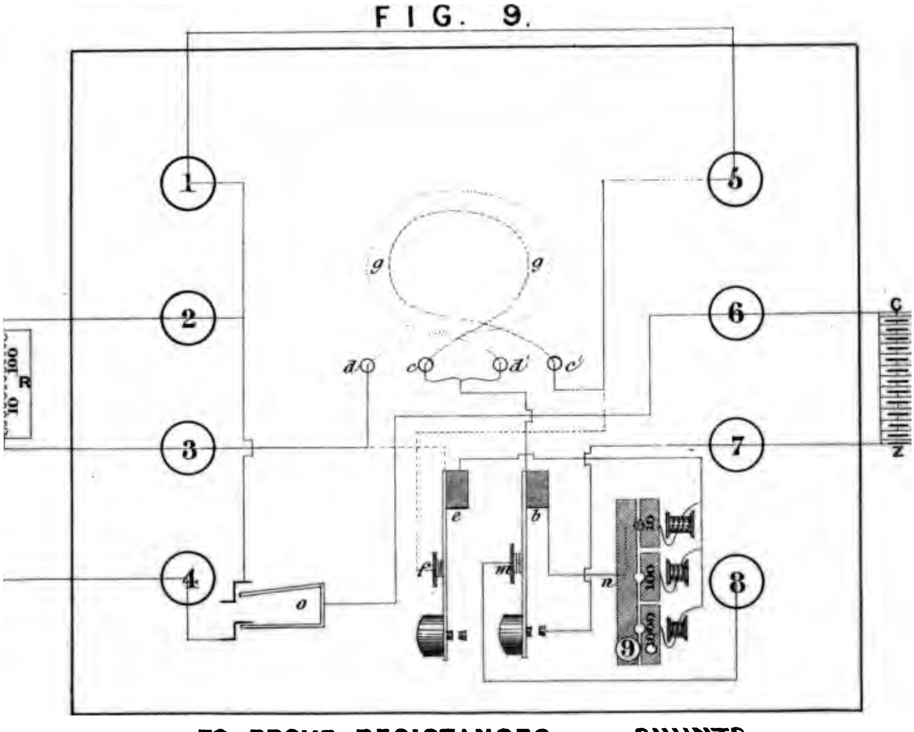
CHARGE AND RETURN-CURRENT
Switch towards "Ordinary Resistance Testing"

FIG. 8.



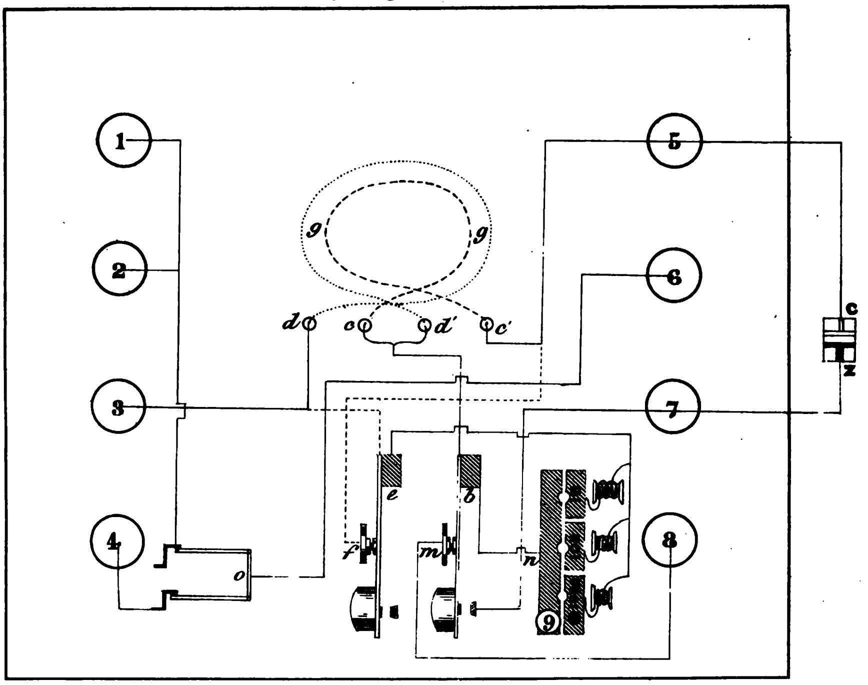
COMPARATIVE CHARGE AND DISCHARGE WITH SHUNT.
Switch towards "Ordinary Resistance Testing"

FIG. 9.



TO PROVE RESISTANCES AND SHUNTS
Switch turned towards "Numerator"

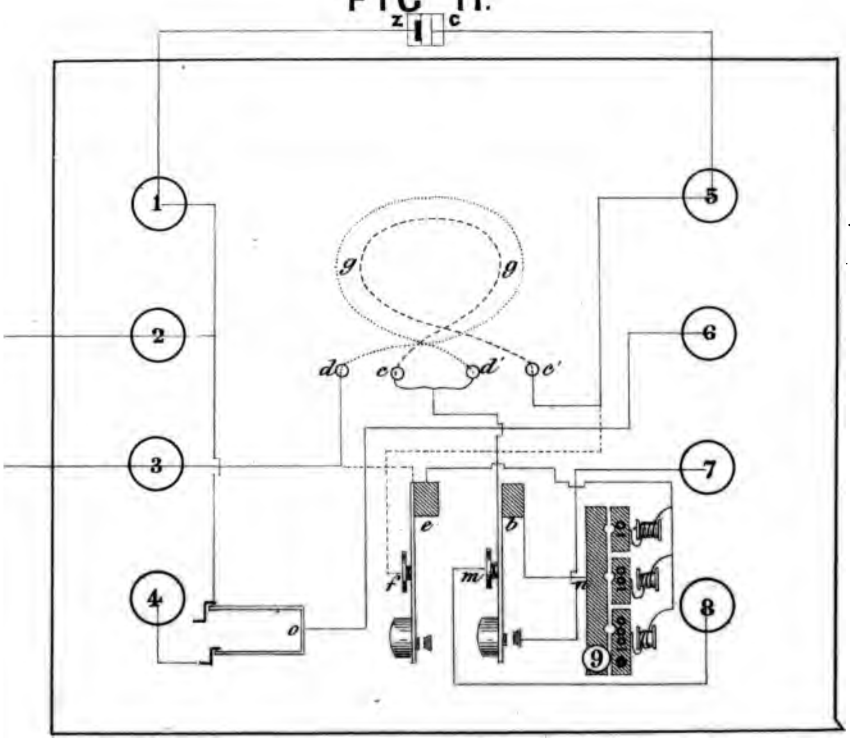
FIG. 10.



TO FIND THE RESISTANCE OF A SINGLE CELL.

Switch towards "Ordinary Resistance Testing"

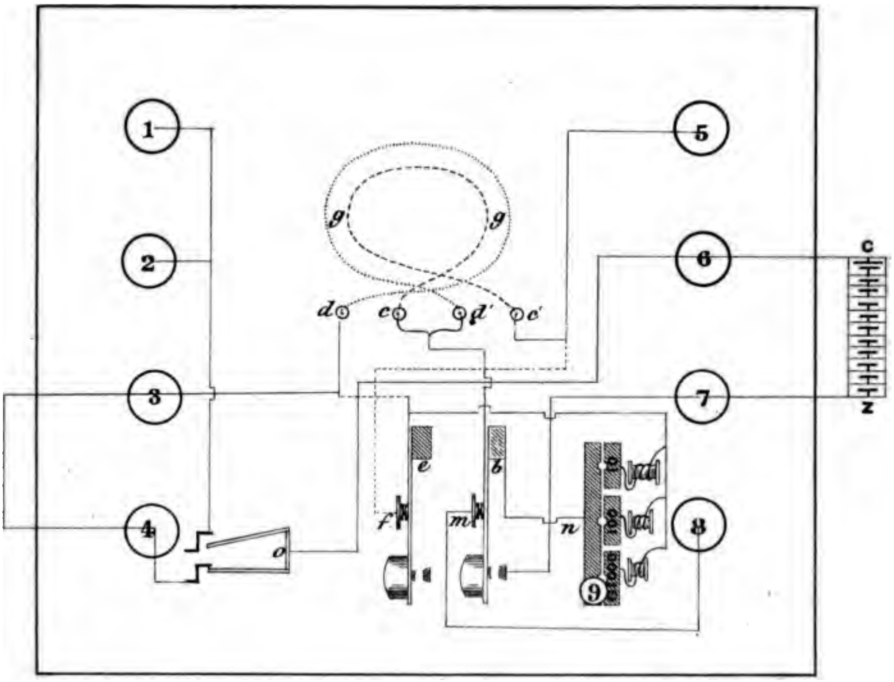
FIG. 11.



TO FIND THE RESISTANCE OF A SINGLE CELL.

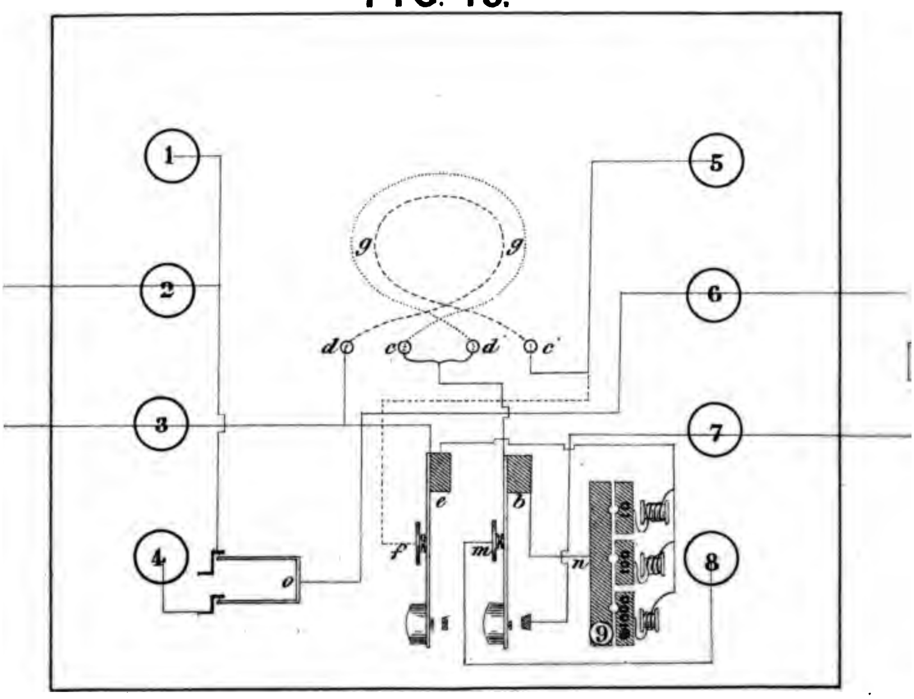
Switch towards "Ordinary Resistance Testing"

FIG. 12.



TO FIND THE RESISTANCE OF A BATTERY.
Switch turned towards "Numerator."

FIG. 13.



TO FIND THE RESISTANCE OF A BATTERY.
Switch towards "Ordinary Resistance testing"